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TACTICAL DECISION MAKING: II. THE EFFECTS OF THREATENING WEAPON PERFORMANCE AND UNCERTAINTY OF INFORMATION DISPLAYED TO THE DECISION MAKER ON THREAT EVALUATION AND ACTION SELECTION

Donald W. Connolly
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Technical Documentary Report No. ESD-TR-61-45 and AFCRL 1100

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Operational Applications Laboratory
Deputy for Technology
Air Force Electronic Systems Division
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FOREWORD

The research reported here is one experiment conducted under one task of Project 4690, Threat Evaluation and Action Selection. Until the Fall of 1961, the technical direction of this project was the responsibility of the Detection Physics Laboratory of AFCRL. This project was conceived and prosecuted by the above Laboratory under the direction of Mr. W. H. Vance, Jr. The particular task under which this research was accomplished, Task 46902, Data Processing for Threat Evaluation, was the technical responsibility of the Components and Techniques Division of the Operational Applications Laboratory of ESD. The present research was the second major experiment in a series designed to study the performance capabilities and limitations of skilled and operationally experienced tactical decision makers in a simulated aerospace surveillance system. This document is the full detailed report of the experiment, part of which has been previously described in an executive summary report. It is hoped that the results will yield information which will assist in the design of future aerospace surveillance systems and the optimum utilization of human talents within such systems.

REVIEWED AND APPROVED FOR PUBLICATION

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ABSTRACT

An experiment was performed in which five highly experienced subjects were required to perform threat evaluation and action selection functions under aerospace surveillance loads of from 60 to 96 incoming tracks. Other influential conditions were the overall flight performance level of the threats and the quality of the surveillance data presented to the experimental commanders.

The most generally influential condition was task load, increases in which caused increased weapon consumption, an increasing but negatively accelerated rate of kill of threats, increasing and positively accelerating amounts of damage and increased reaction time. The load build-up rate beyond which commanders began to lag behind in the selection of counter actions was found to be of the order of 5-6 tracks per minute. The performance level of the incoming threat did not produce clear-cut evidence of effects upon the commander's success at their tasks. Tracks whose position and identifying/descriptive data were 50% - 60% complete and correct were handled in about the same way as tracks represented by perfect information.

The commanders made only small numbers of inappropriate action selections. While the load range tested here began to cause deterioration of action selection performance, no drastic break point was found for any measure. It was found, however, that commanders based their actions upon only the broadest criteria, (e.g., threat vehicle class) and did not (or were unable to) make fine discriminations of relative or absolute threat.

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INTRODUCTION

The experiment reported here is the second major experiment in a series devoted to detailed study of man-machine performance in the aerospace command and control tasks of threat evaluation and action selection (TEAS). Aerospace surveillance could be divided, logically, into several major areas or phases. The first of these may be thought of as raw data acquisition, possibly including filtering and first order processing. The transmission of data from collectors to more central processors can be thought of as distinguishable from collection and processing or as part of either or both. A further area or phase in the surveillance process might be considered to involve data display, evaluation and utilization. A final phase may be thought of as the implementation of command decisions or the "control" processes. The series of experiments of which this is a part has been aimed at study of the evaluation and utilization processes, specifically aerospace surveillance tactical decision making.

In order to study this one phase of the over-all mission of aerospace command and control in comparative isolation and, as far as possible, under controlled and controllable conditions it has been necessary to simulate the whole, integrated process. Early studies (2) were devoted to testing the feasibility of certain approaches. Other studies (3, 5) have been directed to the modification and improvement of the simulation facility.

The over-all background of the whole program requires quite voluminous treatment, which is given in prior reports (2, 4) and which will not be repeated here. It is sufficient to state at this point that the objectives of this research have been to assay the possibilities of "providing fundamental knowledge, concepts, methods and techniques on which to base development of (surveillance) equipment and systems at some future time." (4) More specifically, it has been the objective of these experiments to investigate man-machine capabilities in surveillance decision making and even more particularly, human performance of complex command and control types of activities. The value of knowledge of human capabilities and limitations in this type of behavior, if it can be obtained, and of the general and specific functions whereby such tasks are accomplished should be two-fold. At the very least it should cast light on reasonable (if not optimum) means of aiding such human capabilities or of using them to best advantage in systems of the future. In addition, even general fundamental insights into human performance in this area are desirable if not essential to any future "automation" of all or part of the decision making task.

The first major experiment in this series was concerned with the study of the effects of over-all task load upon the performance of "tactical decision makers" under circumstances where the information supplied them was essentially complete and correct. In addition, the threats which they were required to evaluate and counteract were of a conventional, air-breathing sort. The major task of the "commanders" was the selection, from a varied inventory of varying size, of an appropriate choice of counter weapons, where the outcome of any action was more or less uncertain. Actual evaluation of threat in relative or absolute terms was only a small part of their jobs. The latter experiment is described in a detailed technical report (4).

The present experiment, the second major one in the series, was intended to study the effects on the man-machine decision makers of two additional variables besides sheer task load. One variable consisted of two levels of threat -- slower, lower altitude, somewhat less "lethal" vehicles on the one hand and faster, higher altitude, more lethal vehicles on the other. The detailed characteristics of the threats and the counter weapons may be found in Appendix I. The other variables consisted of a wide variety of kinds and amounts of information reliability. More details of the design of the present experiment may be found in Appendix II.

Both of these additional variables were intended to sample the effects, on tactical decision making, of threat evaluation and action selection situations which were more "futuristic" (in terms of weapon performance) and more "realistic" (in terms of surveillance system performance) than had been the case in previous experiments. The first major experiment was intended, in part, to establish some "base-lines" of decision making performance. The second was intended to ascertain the above effects, if any, and to obtain some insight into the widely known abilities of the human to make surprisingly good use of unreliable and incomplete information. Both of these and succeeding experiments were designed to study a complex, realistic and militarily relevant decision making situation as opposed to the simpler, "neater" and more tightly controllable situations which have been the forte of more basic, academic and theoretical endeavors. Both approaches are necessary; neither is perfect. The "design" employed here is not of a complete classical sort. While a structure of independent and dependent variables existed and controls were exercised (cf Appendix II Section 2) the experiment was not set up as a statistical design. There were two major reasons for this. Firstly, to run a complete or partially complete orthogonal design would have been utterly prohibitive in terms of time and financial costs. Secondly, the interest was in the practical or indicative types of results rather than the inferential statistical type. It may be noted that there is no necessary connection between statistical and practical "significance".

Subsequent experiments in this series will study the performance of man as a "monitor" or "over-rider" of decision making of the same types as studied here since it seems likely that such a role will become increasingly important in command and control systems of the future.

PROCEDURES

The basic apparatus and the adaptations and improvements which preceded this study have been described in great detail in previous reports (5, 2, 4). For the understanding of this study only limited detail is necessary. Schematic site layout and information flow diagrams may be found in Figures 1 and 2. From the position of the tactical decision maker the environment consisted of a "command post" type of facility. The decision maker was seated before a console on which were displayed to him the geographic position situation of friendly and enemy air and space-borne forces. "Targets" or tracks consisted of bright spots on a cathode ray tube screen with a limited amount of track history shown by persisting previous positions. The tracks were capable of being coded into groups according to broad categories by switch selection (e.g., classified by identification, height, weapon type, etc.). The coding was effected by dimming, brightening, focussing or defocussing track spots. Tracks appearing for the first time or tracks whose identification or other ancillary data had been changed appeared as blinking spots. Any track could be selected by number or any track spot could be interrogated with a photo-electric device. Tracks so selected would blink, all other blinking tracks would cease doing so and all ancillary information associated with the particular track (IFF, speed, altitude, vehicle type, the "raid" of which it was a part if any, and the raid size if any) would be read out in alphanumeric form in a bank of small windows at the top of the console. This track position situation and the identifying

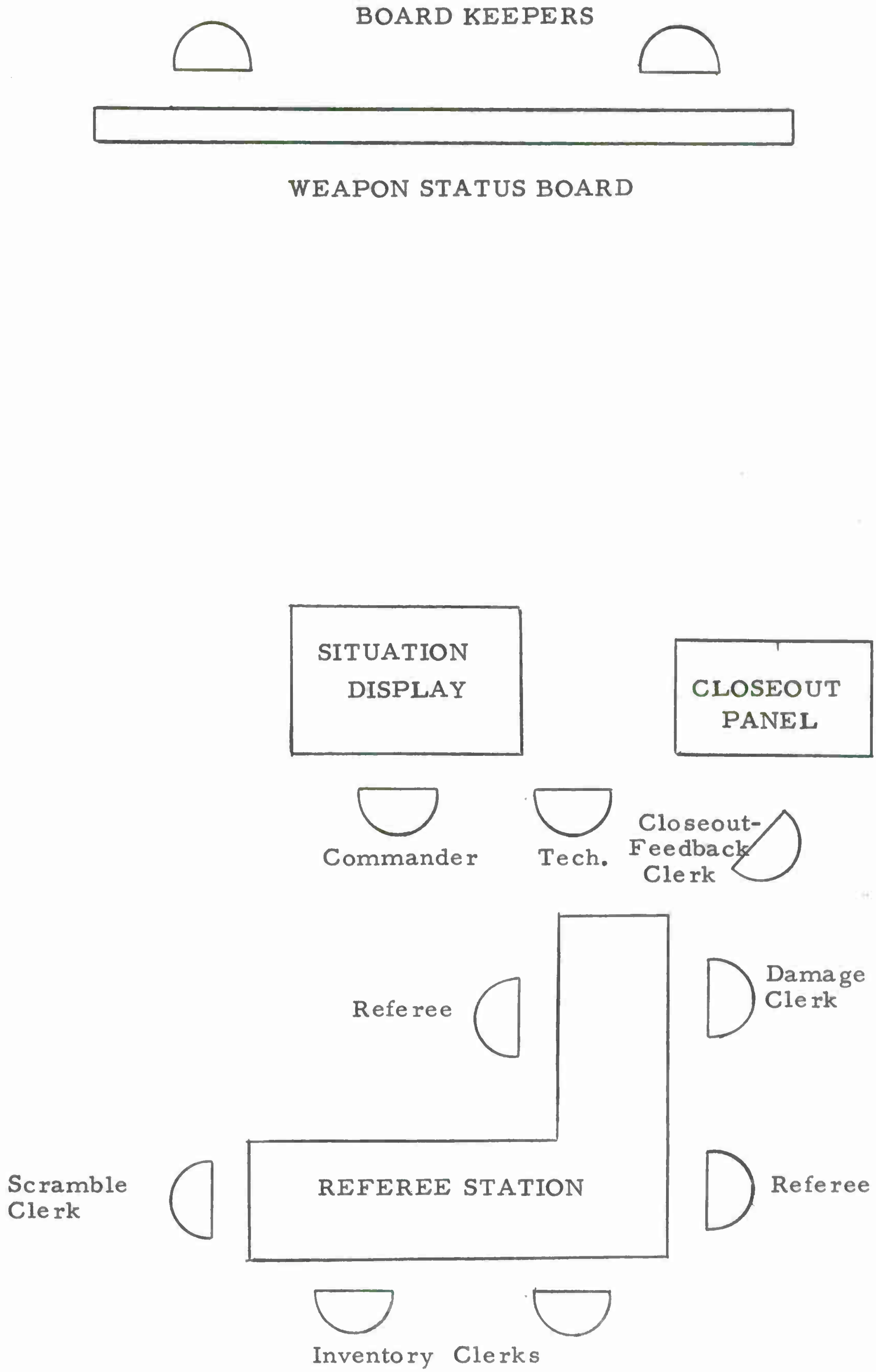


Figure 1. Schematic Site Layout

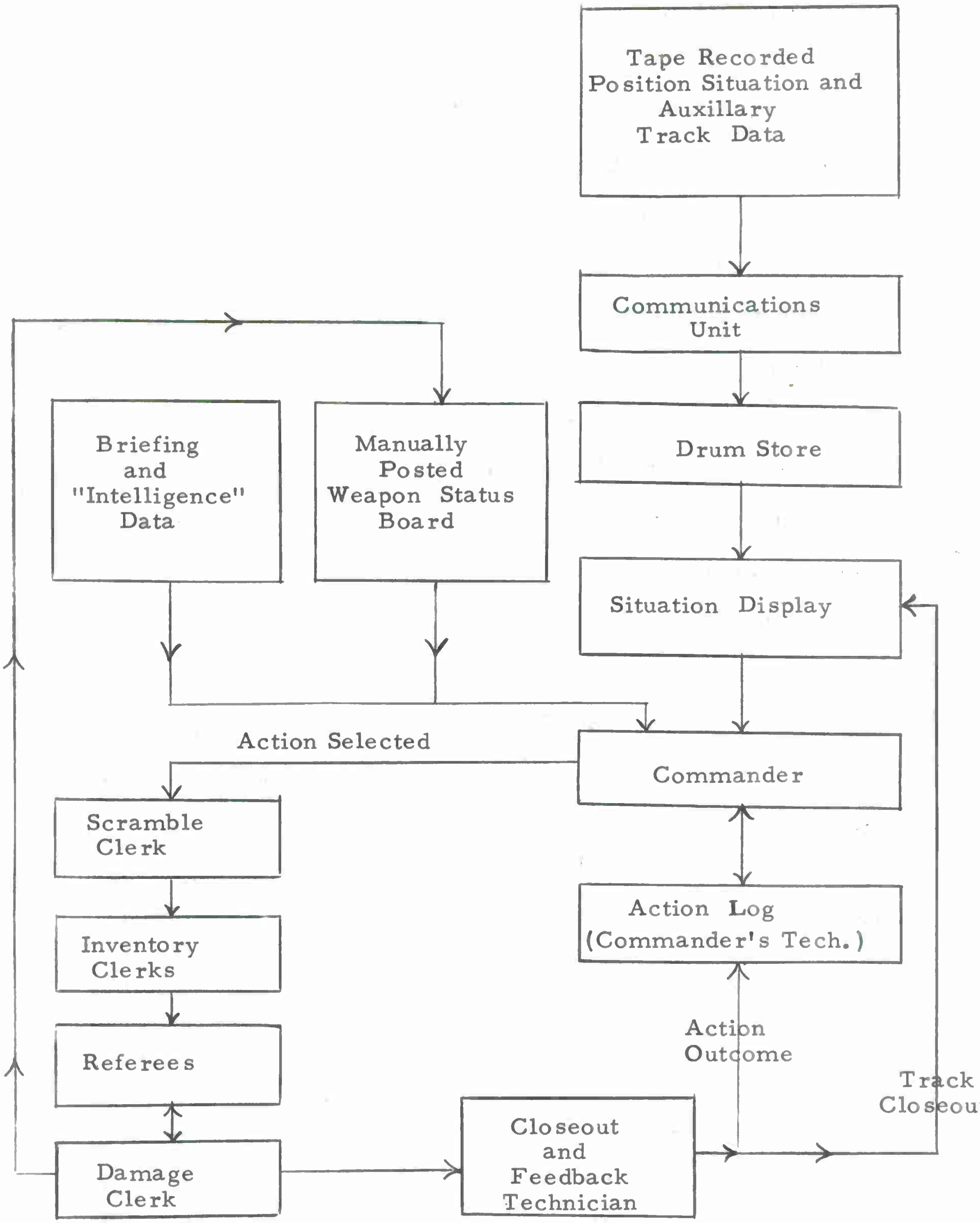


Figure 2. Information Flow Diagram

and descriptive data were supplied from digital recordings on magnetic tape which were previously generated with track generating equipment. Additional detail on the contents of the recorded threat situations may be found in Appendices I and II.

In addition to the electronically generated data described above, the decision maker had other displays. His CRT display was overlaid with a skeleton diagram showing the location of his defensive weapon sites. The total surveillance area measured 300 miles square. There was also a weapon status board (a schematic drawing of which will be found in Appendix III) and an action selection log which was kept by the decision makers technician. The status board in this experiment was manually posted by two airmen technicians behind the edge-lit lucite board.

The rest of the equipment consisted mainly of interior communications (a modified AN/GTA-6) pencils and paper.

It might be best to describe the over-all operating procedure by describing portions of an operation step by step in time order.

1. The tape recorded track situation data were fed into the digital communication system, thence to a drum store and thence to the situation display. The first targets appeared at problem time zero, at which time the weapon status board appeared as shown in Appendix III.

2. The tactical commander would interrogate the first tracks one at a time. On the basis of position, identification, kind, speed, etc., he would act against each target.

3. The action selected consisted of the track number to be attacked, the weapon kind, the site from which it was to be drawn, the armament type and the number of such weapons. The mode of employment was assumed to be in a single flight group unless otherwise specified (cf. also Appendix I).

4. The action selected was simultaneously recorded, together with the time at which it was selected by the commanders airman technician and by the "scramble clerk" at the referee station.

5. The scramble clerk passed the slip with the action data to one of two inventory clerks (one for missiles, the other for aircraft assignments). Appropriate deductions from inventory were communicated to the weapon status board where the board keepers made the necessary changes.

6. The inventory clerks passed the assignments to one of two referees (one for higher numbered tracks, the other for lower numbers) who evaluated the action selection. Referees had two sheets, containing distributions of "kills" and "misses" for nearly any action which could be selected for each track. A sample referee sheet with detailed explanation may be found in Appendix III. Further details of general scoring procedures may be found in Appendix I.

7. The outcome, if a kill, was passed to the closeout technician who would:

(a) cause the track in question to be removed from the system at the time specified by the referee (this time also was preplanned and was a function of the intercept time which in turn depended upon the speed of the weapon assigned and the distance to go at scramble time) and,

(b) transmit the outcome information to the commander (via the commanders technician) at outcome time.

8. The outcome, if not a kill, was also transmitted to the commander at the outcome time, but without closing the track out of the system.

9. The damage clerk had a running record, by time, of all pre-programmed potential damage which could be inflicted by any track. All assignments, therefore, were passed through the damage clerk position. If a track capable of inflicting damage was killed prior to causing the damage, no losses were assessed. Otherwise, the penetrated defensive weapon site was closed due to damage for pre-planned periods of time and/or defensive weapons were removed permanently from the inventory of the site. These damages were posted on the weapon status board.

Experimental problem runs had durations of 35 to 45 minutes, depending on the particular track situation presented and the success of the particular commander in dealing with it. The details of the experimental plan may be found in Appendix II.

The commanders in the present experiment were selected as the five most proficient of the nine who had served in the first major experiment. One of the main interests of this part of the program has been to study as uniformly high a grade of tactical decision making as possible, since it has been felt that good performance would be more revealing of genuine and general problems and suggestions for their solution. The five commanders (or tactical decision makers) in this experiment were all First Lieutenants and Captains with extensive AC&W experience in operational sites and in the Experimental Sage Sector as well as in prior experiments of the present series. They were briefed in detail on the purposes of the experiment (except for such knowledge of experimental conditions as would vitiate the results if foreknown) and on their duties (cf. also Appendix I). Numerous practice problems were run with each commander prior to the collection of the data described below. These served the useful purpose of accustoming the commanders to the specific situation and of "shaking down" and solidifying experimental procedures.

As explained in Appendix II where considerably more detail may be found concerning the construction of the experimental threat evaluation - action selection problems and the factors under investigation in the present study, it was considered important to control the effects of "practice" insofar as their systematic effects on performance were concerned. While the main design was intended to be fully counterbalanced with respect to load and threat performance level it was not always possible to adhere to this plan for logistic reasons. The experimenters were forced by circumstances to make use of the various commanders when their time could be made available rather than vice versa. Added to the factor of personnel availability the vagaries of equipment malfunction literally forced a certain amount of catch-as-catch-can scheduling. Experience with and foreknowledge of the liklihood of such difficulties in addition to the reasons given in the Introduction, were further, though not major, reasons why no attempt was made to fabricate or execute one of the more complex classical experimental designs.

RESULTS AND DISCUSSION

During the actual data collection runs detailed records were kept of all the actions selected by the commanders, the evaluations of these actions and their outcomes. These records included assignment slips, referee sheets (cf. Appendix III) and photographs of the weapon status boards. The three general headings under which performance measures or indicators fell were the damage sustained, the cost in terms of defensive weapon usage and the success of the commander in reducing the forces of the enemy. These have been referred to in previous reports as damage, cost and kills. With the records generated during runs it was possible, afterwards, to assemble a complete set of data on everything that happened with respect to every track. Data extracted for each track included:

1. Damage data:

(a) Actual problem time at which damage was inflicted,

(b) Actual number of weapons removed from inventory as a result of damage,

(c) The amount of time the damaged site was out of operation.

2. Cost - For each assignment there was recorded:

(a) The kind of defensive weapon that was assigned (including site, the kind of a/c or missile and its armament),

(b) The number of weapons assigned and the manner of employment (i.e., in single flight, at trail, salvo, etc.),

(c) The number of weapons actually used (generally less than assigned since the first of a succession of weapons might kill and the remainder be returned to inventory),

(d) The time delay in assignment (i.e., actual time between onset of track and assignment time),

(e) The "time interval" (i.e., which five minute time period during the problem) in which the assignment was made. This category of data was primarily used for sorting purposes,

(f) The time to intercept. This was the time, in minutes, between assignment and outcome whether failure or success,

(g) Kill probability. This was the two digit designation of the probability distribution which was sampled in assigning a successful or unsuccessful outcome to the particular action selected (cf. also Appendix III).

3. "Kills" - For each track there were entered:

(a) Overall outcome, i.e., killed or missed by any or all assignments against it,

(b) Ancillary outcome. There were six additional categories of outcome in additions to kill and miss. These included the one-class and two-class overmatch (cf. Appendix I) the undermatch and assignments made too late to have any possibility of success (either due to the permanent loss of the target by the system or an impossible "tail chase") as well as "previously killed".

In addition to these performance data categories there were numerous items of identifying and categorizing information relating to each track. All of these (including track number, threat kind, onset time, damage potential, etc.) were entered into punched cards together with the performance data. This process permitted rapid and flexible data processing. The results to be described below, it must be pointed out, are almost exclusively group results. That is they are summaries and averages for all commanders under the conditions specified.

It will be remembered that the principal factors whose effects were under investigation in this study were load, data quality and threat performance levels. Figure 3 is a summary of the overall effects of the load variable. These results have been described and discussed in some detail in a preliminary summary report of the present experiment (1). The general pattern of load effects on the summary performance measures (damage, cost and kills) is that which would be expected. Weapon usage is seen to rise with rising threat load, but at a decreasing rate. The total number of threats successfully countered shows a similar relationship with load while damage, conversely, shows a definite positive acceleration. All of these general findings indicate an approaching saturation of the ability of the single commander to keep pace with the total increasing threat situation. None, however, shows evidence of a sharp break or drastic deterioration. More detailed treatment of the three major classes of performance measures as well as some additional indices will be found below.

Weapon Assignment and Usage:

Table 1 presents a summary of the percentages of the total inventory of weapons available to the commanders which were actually assigned, on the average, against the incoming threats as a function of first and second trial at each load and separately for the two levels

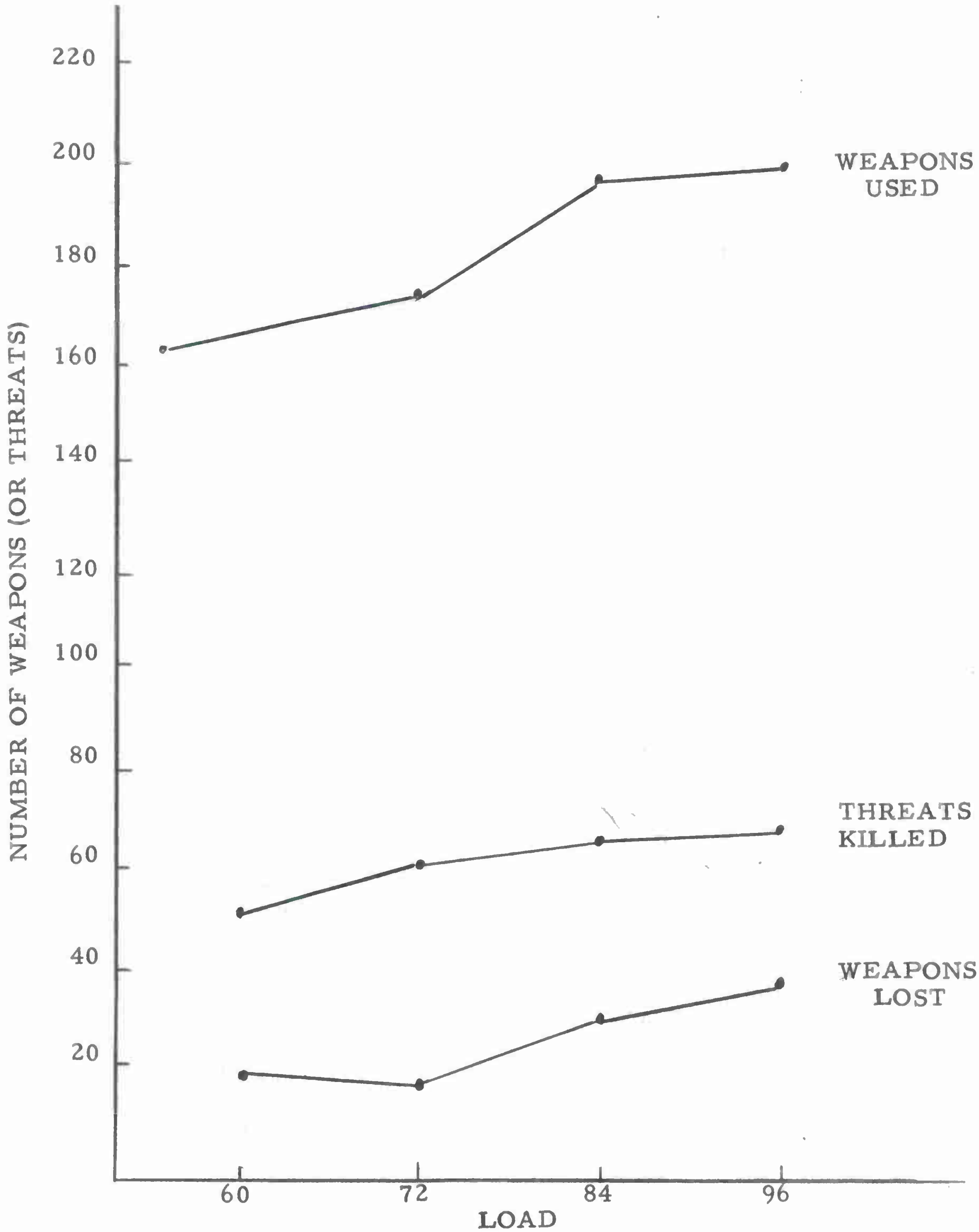


Figure 3. Summary Performance: Cost, Kills and Damage

of threat performance ("Tape I" and "Tape II"). Only one combination of 96 tracks was possible with each tape and these maximum loads were not replicated. The major difference between the "Tapes" was in the average speed of the threat tracks (cf. also Appendix II). It may be seen in Table I that there is a tendency to assign more weapons against essentially the same number of threats on second replication of load 84 in Tape I and at all replicated loads in Tape II. In

TABLE 1

Percentage of Weapon Inventory Assigned

Load	60		72		84		96	
Tape	I	II	I	II	I	II	I	II
Replication 1	76	65	79	78	80	91	88	91
Replication 2	76	74	79	81	85	95		

addition except for load 60, more weapons were assigned against a given load (number of threats) in Tape II than Tape I.

There are several possible factors in explanation of these results. One major possibility lies in the order of presentation of the problems. While the order of presentation of loads within a tape was counterbalanced (working from low to high on first replication and from high back to low on second replication) or scrambled (quasi-random order) to control learning effects, it is patent that the first replication always preceded the second. Also, most frequently the commanders were presented with the Tape I problems before the Tape II problems of equivalent load. The experience factor may account for some of the increase in weapon assignment with replication.

As far as the increase from Tape I to Tape II, however, analysis of the data on the "core" tracks (the set of identical tracks which appeared in both tapes - cf. Appendix II) did not reveal any systematic differences in the numbers of weapons assigned against them as a function of the tape in which they appeared. Other data described below also suggest that the difference here between tapes is not merely a "practice effect."

Other factors which tend to illuminate the finding that larger numbers of weapons were assigned against threats in Tape II may be found in the general manner in which assignments were made. First, it should be pointed out as shown in Figure 4 that the two tapes appear to produce two fairly distinct patterns of assignment behavior at all but the lowest load. Note that a substantially greater proportion of the total number of threats in Tape II is ignored than in Tape I (i.e., no action was assigned against them). One would expect this to result in the assignment of fewer weapons in total. Note also that less of the tracks in Tape II were first dealt with in "raid" assignments, despite the fact that nearly equal proportions of tracks in both tapes appeared in "raids". In raid assignments groups of tracks could be handled by a single action selection and the use of fewer weapons in total could produce the same number of kills as a larger number of weapons assigned track-by-track (cf. also Appendix I). The implication here is that, since a larger proportion of the threats in Tape II were handled as individual tracks and since this mode of assignment would be expected to require assignment of more weapons that more weapons in total would be assigned against Tape II threats. The latter expectation

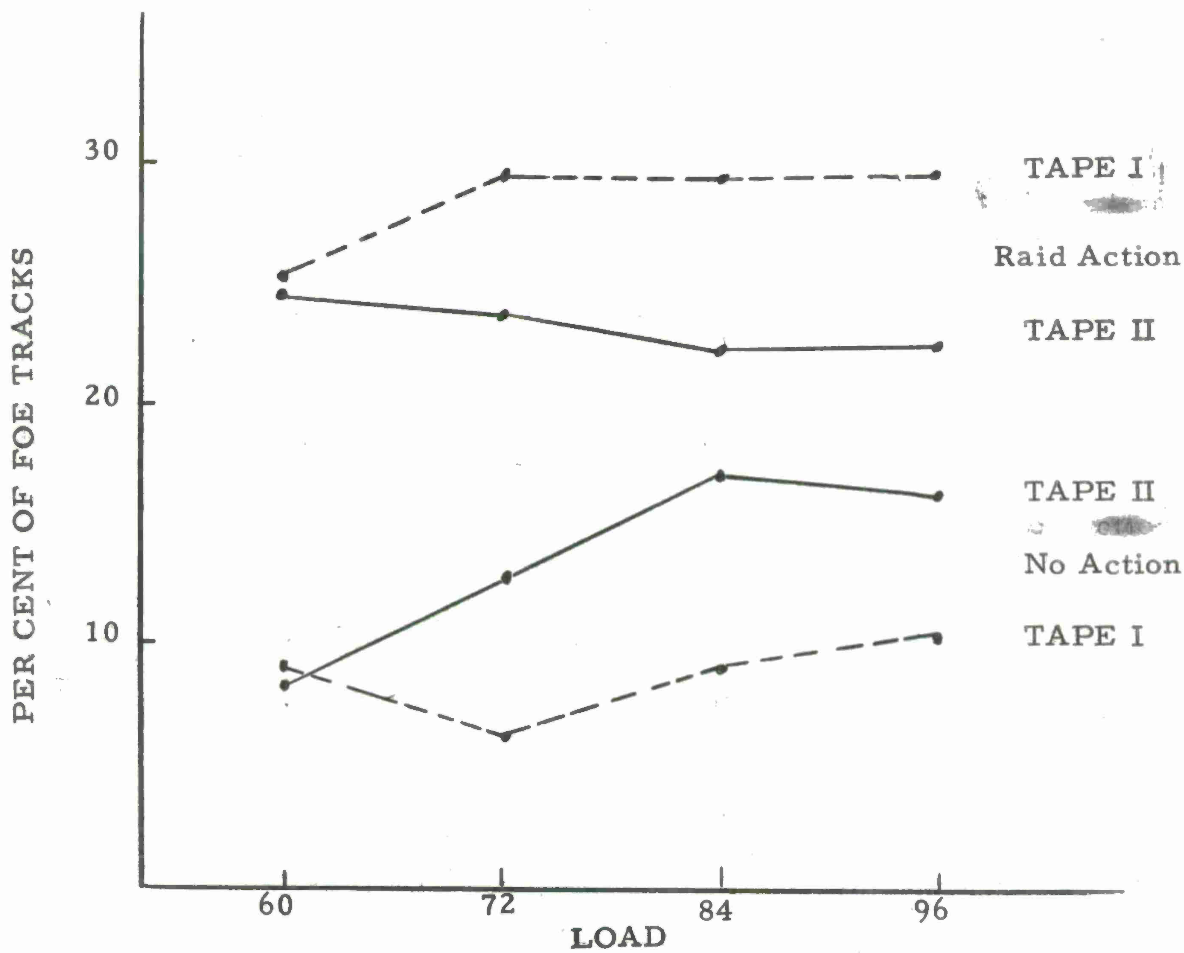


Figure 4. Proportions of Foe Tracks Not Acted Upon and First Acted Upon by Raid Assignment.

was borne out by two additional replications (beyond those shown in Table 1) of 60 track problems using each of the two tapes. These replications were subject to the restriction that "raid" type assignments were not permitted and all assignments had to be made on a track-by-track basis. For the Tape I, load 60 problems this restriction (plus possibly some of the experience effects noted above) produced an average of 7% more weapons assigned.

For the Tape II, load 60 problems the "no raid assignment" rule produced an average of 20% more weapons assigned in total. Since in every instance the commanders faced both of the Tape II, load 60, replications three and four before dealing with the corresponding Tape I replications the apparent decrease in weapons assigned as a function of experience here tends to vitiate the "learning" hypothesis as a general explanation of the weapon assignment picture.

Now the two factors cited above (i.e., decrease in weapons assigned due to increase in number of tracks ignored and that of increased assignment due to less economical methods of handling tracks) are plainly antithetical. Indeed, they might be expected further to have mutually cancelling effects. One clear-cut possibility of an explanation of the generally higher weapon assignment (and actual use in "battle") shown in Figure 5 to be characteristic of the Tape II results may be found in the fact that, over-all loads combined, 40% more weapons were assigned in fourth and subsequent assignments (as opposed to the total in 1st, 2nd and 3rd assignments) against Tape II tracks.

Slightly more weapons also were assigned in the first three

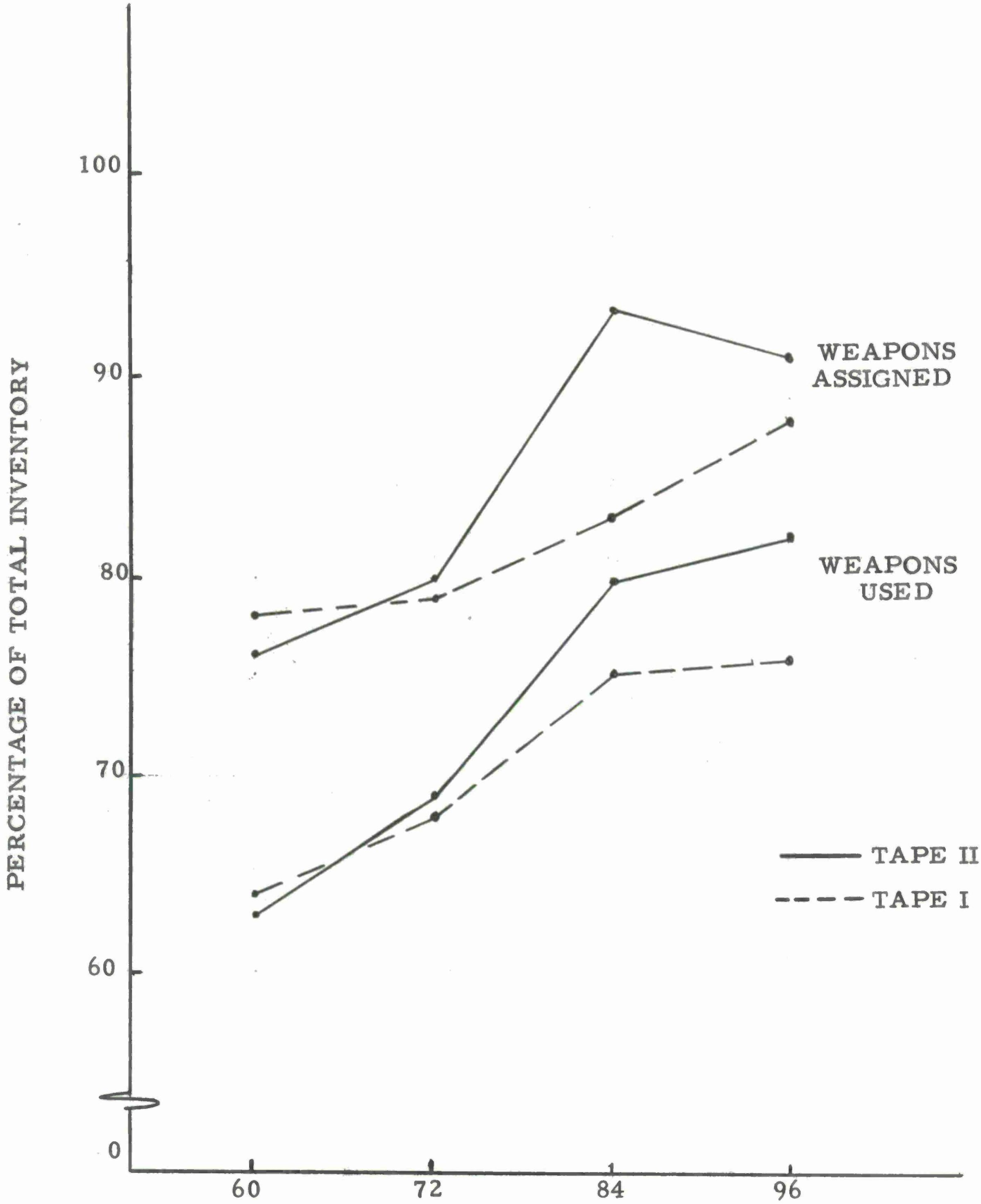


Figure 5. Percentage of Counter Weapon Inventory Assigned and Used as Functions of Threat Performance and Load.

assignments, on the average, in Tape II than in Tape I. This reflects the less economical track-by-track type of assignment which has been found to be more frequent in Tape II.

Aside from possible learning effects due to order of presentation (indications of which here are somewhat contradictory and by no means certain) a tentative conclusion may be reached as to the cause of this difference in assignment pattern. The conclusion is that the main difference between the tapes, i.e., threat performance level - could be responsible. While the threat situation as defined by number of tracks entered as of a certain time was not greater in Tape II the situation developed somewhat faster in terms of the speed with which threat vehicles moved. One-eighth of the aircraft tracks in Tape II were at speeds as much as 25% greater than their counterparts in Tape I and all threats on the average moved at a 12% higher speed in Tape II (cf. also Appendix II). The more rapidly developing situation (in terms of track speed) and the tendency to make larger initial assignments and reassignments which this could have produced is a probable explanation of the generally higher weapon assignment and usage against Tape II tracks.

Figure 6 shows the rate of build-up of the surveillance track load in terms of the average number of tracks entered per minute for the first ten minutes of the problems. These averages include both situation tapes and all replications. Figure 7 shows the problem time at which the commanders, on the average, had made a number of action assignments equal to the total number of tracks entered up to that time. The latter is an indication of how long it took commanders

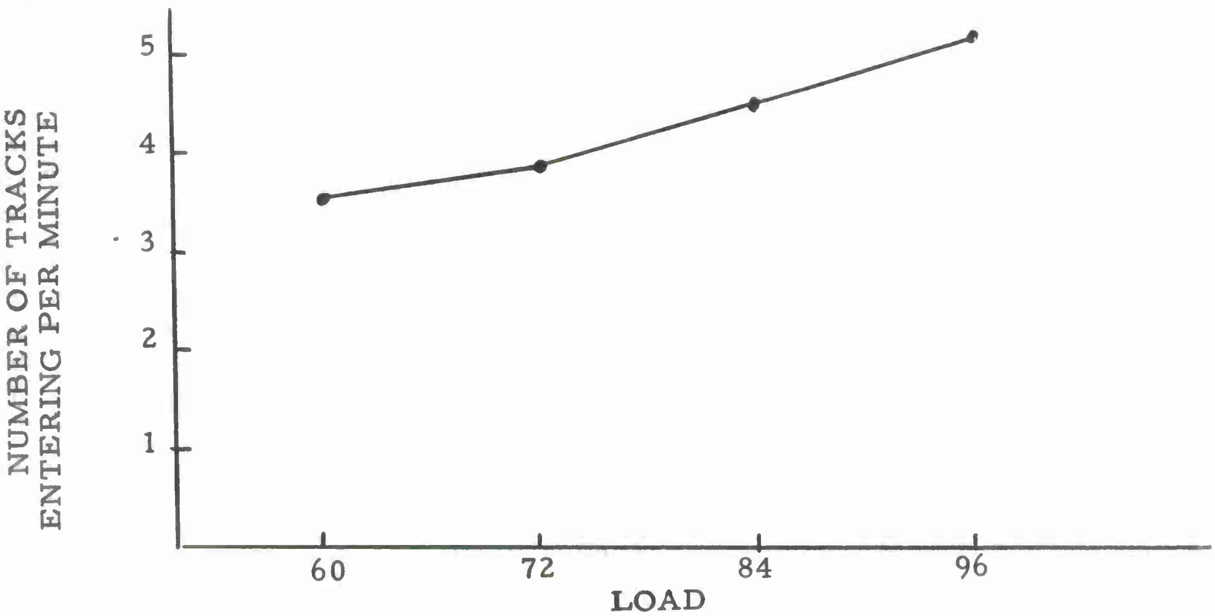


Figure 6. Rate of Load Build-up for First Ten Minutes of Problem.

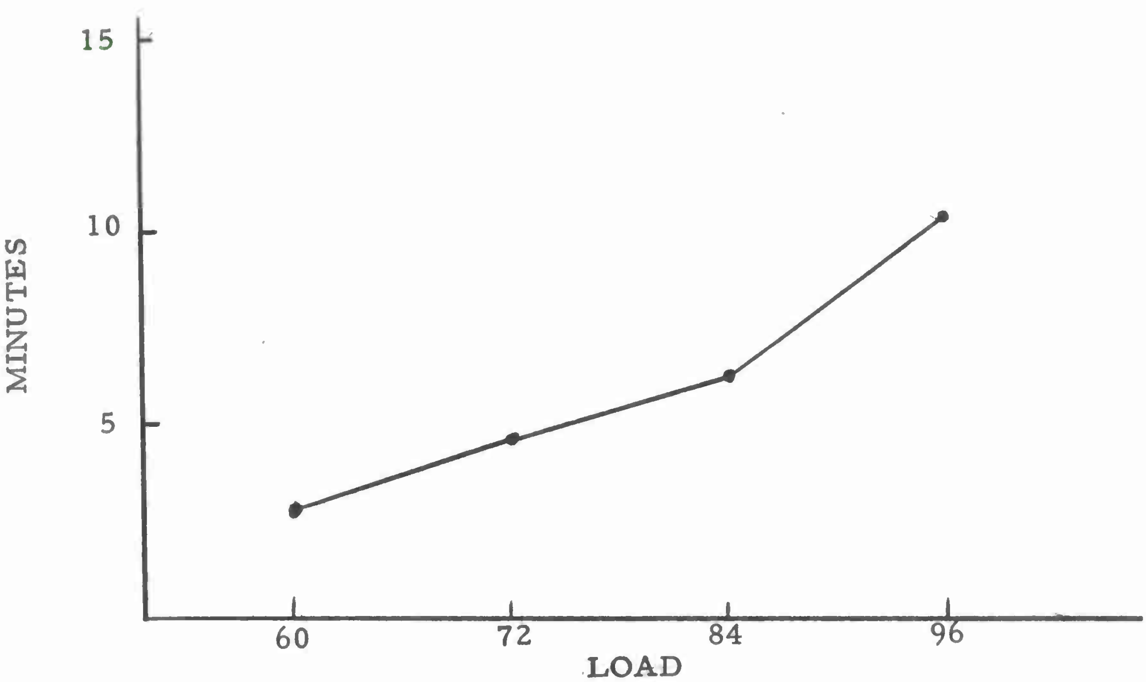


Figure 7. Average Time Taken by Commanders to Make a Number of Assignments Equal to the Number of Tracks Present.

to "catch up" with the developing situation. It is worth noting that, while the increase in load build-up rate was linear, the time taken to "catch up" with it exhibits a marked increase between load 84 and load 96. The load build-up rate at which the abilities of the commanders to "keep pace" or to "catch up" with, and overtake the developing situation appears to be of the order of five tracks per minute. In fact, the actual number of assignments made per minute in the first five minutes varied between 4 (at the 60 track level) and 6 (at the 96 track level). Since the problems started with an "unassigned - against" backlog of five to ten tracks as a function of load this first time sample represents the period of most concentrated activity to simply "catch up". Five or six judgments and action selections of the sort required here is probably the maximum that can be expected per minute.

The actual usage of weapons by weapon class as a function of load is shown in Figure 8. The numbers used are quite proportionate to the numbers available. At every load the largest class (high-yield aircraft) was most frequently used, the next largest class (low-yield missiles) next most frequently used and so forth. In addition, all classes are used in increasing numbers with higher loads. There is some slight evidence for a "tapering off" in the use of all classes from load 84 to load 96, which (as may also be seen in Figure 3) most probably indicates that the load is requiring the <u>use</u> of a total number of weapons approaching the total number available. Note that the totals in Figure 8 would be uniformly lower than those in Figure 3 since Figure 8 includes weapons used only as a result of the first three or less assignments against each track while Figure 3 includes all

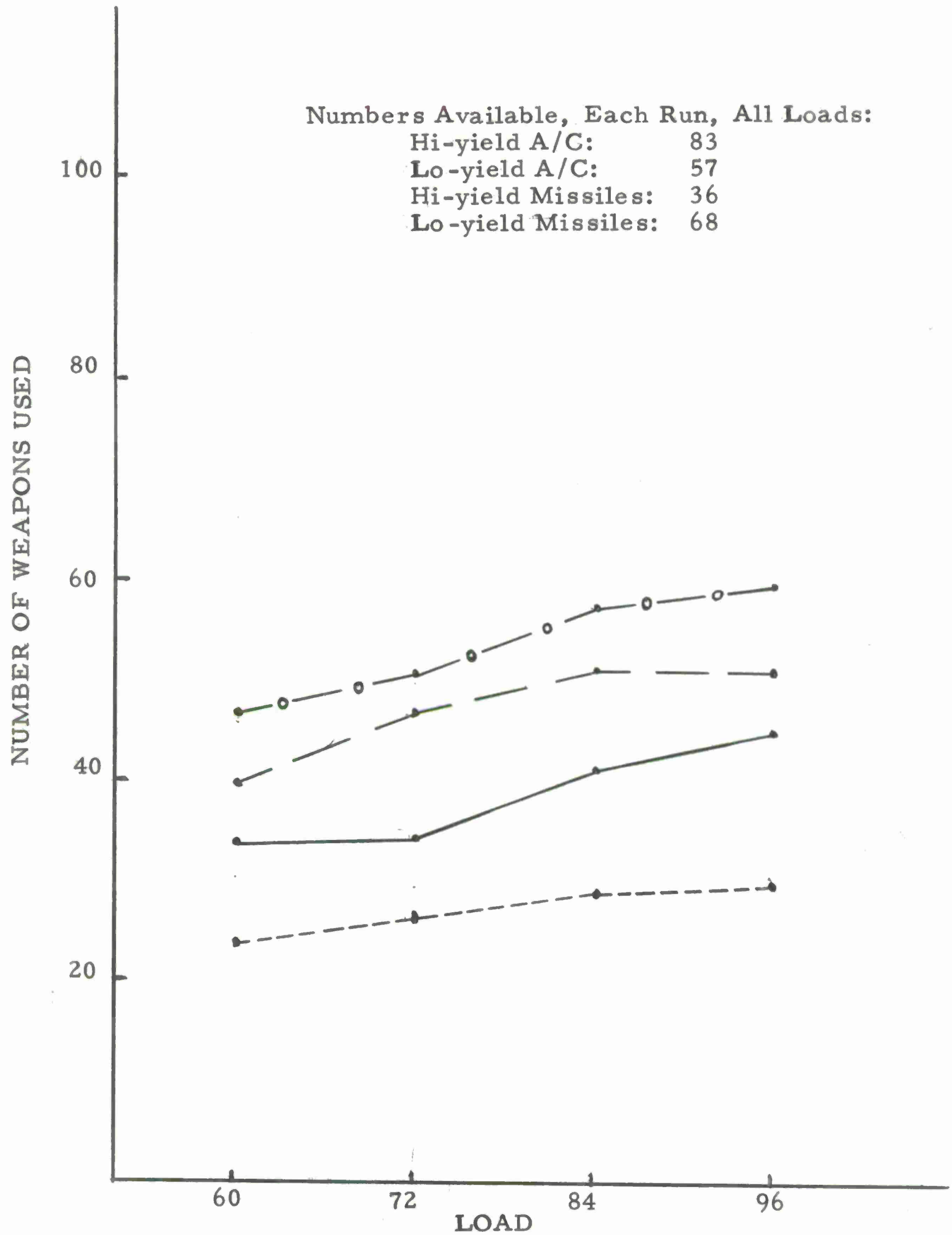


Figure 8. Average Number of Weapons Used, by Class, in First Three Assignments.

assignments. The difference is not great, however, fourth and subsequent assignments contributing an average of 19 more weapons used at load 60 and an average of 16 more at load 96. That one limiting factor at load 96 was "available inventory" is indicated by the fact that the grand total of 200 weapons (see Figure 3) used, plus 36 weapons lost due to damage at this load equals 236 whereas the total available was 254.

It should be pointed out also that high-yield aircraft showed a tendency to be the "weapon of choice" against raids. In general, raid-type assignments were permitted only with the use of high-yield armed weapons - either missiles or aircraft. The commanders tended, in this experiment, to use high-yield armed aircraft (of which more than twice as many were available) rather than missiles against raids. The net effect appears to have been to assign and use the high-yield aircraft in such a way that the general proportion between availability and usage as noted above, was maintained. That is, while the 60 to 75 per cent usage ratio holds for all classes of weapons except high-yield aircraft in track-by-track assignments when raid-type actions are added in it also holds for high-yield aircraft.

In addition to threat performance level (cf. "tape" above) and track load this experiment included another factor, internal to all "problems" or threat-evaluation action-selection situations faced by the commanders. This factor was data quality. Care was taken to provide an approximate balance or average quality of information presented so that no particular combination of other conditions (load, tape or replication) would be affected by extremely good or poor overall data quality (cf. also Appendix II). The major purpose of the planned degradation of the information on which the commanders' decisions had to be based was to take into account more "realistic" conditions. Previous experiments (2, 4) had presented position situation and identifying or descriptive data which were complete and correct. It is hardly to be expected that such a condition would obtain in actual field operations.

A subsidiary purpose of the data quality variation was to obtain, from the results, some knowledge of the effects of incomplete or incorrect information on the decision making behavior of the commanders. In general, these effects were somewhat erratic. Table 2 summarizes the obtained relationships between weapon usage per track and the various kinds and amounts of information quality. Number of weapons used is the measure appropriate to this particular section. However, it reflects directly the number assigned (and is most frequently somewhat smaller) which, in turn, reflects the attention given by the commanders to tracks of varying data quality. Generally speaking, there were no differences in such things as initial reaction time or other performance measures since all tracks were presented with correct and complete data for the first two minutes of their lives. Obviously there is no sense in studying performance against threats not yet presented.

TABLE 2

Mean Number of Weapons Used Per Track as
Function of Data Kind and Quality

	Per Cent Data Complete and Correct							
Kind of Data	10	20	30	40	50	70	80	100
NTD[1]	3.1	2.0	1.8	1.6	2.4	2.2	1.8	
F[2]	.9	2.3	1.4	2.1	2.1	1.7	2.6	
ANC[3]	1.3	1.9	1.8	1.5	2.6	1.8	2.6	
F-NTD[4]	1.6	.8	2.8	1.6	2.6	2.7	1.7	
All								2.2

Notes:
1. NTD tracks did not move for varying proportions of their lives.
2. F tracks faded or failed to appear for all but the stated percentage of time.
3. ANC tracks were supplied with erroneous IFF, speed or altitude data.
4. F-NTD tracks either faded or stopped moving, or both.

First, it should be pointed out that there were only very small samples of each category and amount of data unreliability within any one combination of other conditions (except for the 100% complete and correct tracks which were the largest category). More than half the tracks were presented with 70 or more per cent of their data complete and correct. For this reason data from all loads, both tapes and all replications are included in the average numbers of weapons used shown in Table 2. Aside from the rather great variability within kinds of data or quality levels, only a few observations are possible. First, above about 50% complete and correct the number of weapons used per track seems to cluster fairly reliably around the average number for 100% tracks for all classes of information. Also, the "fade" tracks, overall, had the fewest weapons used against them. It is safe to say that, if a track is out of sight it will tend also to be ignored to a greater or lesser extent. Vehicles which stop in their tracks (NTD tracks) tend to elicit the use of about as many weapons, on the average, as tracks that act more normally. In general, however, with respect to weapon usage no really solid and consistent behavioral effects emerged except that even the very poor quality tracks attracted substantial attention and action from the commanders.

A sample of tracks in three data quality categories (10%, 30% and 100%) was studied in detail for the kinds of weapons which were assigned against them. The general tendency of the commanders were to assign aircraft in their first action against all categories (60-70% of first actions used aircraft weapons). Against the 100% complete and correct tracks second and third actions used missile counter-weapons approximately 60% of the time. Second and third actions against 10% tracks, however, predominantly employed aircraft. Against 30% tracks the commanders went to missiles on second assignments and then back to aircraft on third assignments, but in both cases the ratio of missile to aircraft assignments was much closer to 50-50 than was the case with either 100% or 10% tracks. Since missiles, on the average, had a higher kill probability (other factors such as delay in assignment, and number assigned being equal) than aircraft in this study the tendency to assign and reassign aircraft weapons against targets with very poor data quality could indicate an unwillingness to commit the scarcer and more potent missiles against dubious tracks. When the commanders were debriefed, however, they generally reported that the information presented to them was of a much higher quality than it actually was. The commanders were so immersed in the detailed effort to deal with threats one by one or in raid groups on the basis of criteria which were more demanding of attention (i.e., threat category, speed, position relative to defended areas, etc.) that they were unable to appreciate the more elusive details of data quality. Without special and attention-getting indication of data quality (not present in this study) it is unlikely that poor quality tracks would elicit specialized handling.

Damage Sustained:

Table 3 contains a summary of all damage data classified by "tape" and load. The percentages of weapons lost are based on the actual total numbers removed from available inventory as a result of hostile penetrations and "bomb-drops" as related to the total inventory initially available. The "down-time" percentages are based on the

TABLE 3

Per Cent of Weapon Inventory and Per Cent of Potential "Down-Time" Assessed as Damage

		Load			
%	Tape	60	72	84	96
Weapons Lost	I	8.7	7.2	11.8	14.1
	II	6.6	7.3	10.2	14.6
% Down Time	I	34.0	29.9	26.9	47.3
	II	21.4	25.1	29.7	33.8

actual number of minutes (total) that sites were closed (i.e., their weapons were unavailable for use) divided by the total potential closed time that was built into the problems (cf. also Appendix II). IRBM and bomber-type threats were capable of inflicting heavy damage in both categories. Fighter-bombers could not cause total destruction of a penetrated site nor long periods of "down-time". Fighter-type threats were capable of only very limited weapon destruction and could cause no "down-time". If no counter-actions whatever had been taken a complete loss of all weapons in the initial inventory would have ensued and one or more sites would have been placed "out-of action" for totals of 120 to 200 minutes (depending on load).

While weapon loss did not differ consistently or greatly from tape to tape it rose by a factor of just under two from the lowest to the highest track loads. Since the potential loss was 100 per cent at all loads, the actual damage sustained (i.e., maximum 14.6%) was not great. This was true despite the fact that the actions of the commanders did not differentially kill tracks programmed to do actual damage (as opposed to those which were not so programmed) as will be seen below.

"Down-time", on the other hand, except at load 84, was greater for Tape I problems than Tape II problems. While some of the same possibilities of "practice effect" cited in explanation of the weapon usage results above would also apply here there is at least one additional cause. In both tapes the single category of threat which caused the largest number of weapons lost in nearly all instances was that of fighter penetrations. These threats were capable of causing the loss of only one weapon. Since the commanders concentrated upon countering the IRBM and bomber-type threats and tended to defer or omit action against fighter-types comparatively many fighters were permitted to penetrate and cause damage. This last was true in the case of both tapes and all loads. When other threat classes were considered, however, closer study revealed that bomber penetrations occurred more frequently than fighter bomber penetrations in the Tape I problems whereas the reverse was true in the Tape II results (see Action Outcomes below). Thus, while the programmed penetrations of these types of threats was equal in the two tapes, the actions of the commanders were such that bombers were prevented from causing damage to a greater extent in Tape II problems. The greater "down-time" found for Tape I is at least partly explainable by this fact, since the damage potential of bombers and fighter-bombers differed as far as the two categories of damage was concerned. Fighter-bombers, on the average, were capable of causing only about one-half the amount of "down-time" as bombers. While the weapon destruction potential of fighter-bombers was also less, many "potentials" in this regard were of a percentage type. Thus, in the event that a bomber or fighter-bomber penetrated a defended area a percentage of the weapons then on the ground at the penetrated site would be removed from available inventory for the remainder of the run. Since few penetrations of either class (bombers or fighter-bombers) were scheduled before problem time 10-12 minutes and since forty to fifty assignments (mostly of more than one weapon each) had generally been made by these times (cf. Figure 7 above) a large proportion

(33-50%) of available weapons had been committed and/or expended. Thus, both bombers and fighter-bombers might find numbers of weapons available for destruction sufficiently small that overall totals destroyed by either would not differ greatly. For instance, the difference between 25% and 50% of four weapons is only one weapon. Such a difference could be obscured by the large numbers of single-weapon losses caused by fighter penetrations (cf. above). Therefore the larger quantities of "down-time" in Tape I problems were probably due to the more frequent bomber penetrations. The apparent change in tactics by the commanders (more concentration on bomber threats) which is involved here could be considered a species of "learning effect" but is probably related, at least in part, to the pattern of differences between tapes in weapon assignment and usage discussed above.

Action Outcomes:

As noted previously there are two basic outcomes possible for every assignment, either kill or miss. These outcomes were selected from samples of probability distributions pre-programmed on the "referee sheets" (cf. Appendix III). Certain other evaluations of assignments were also made. If an aircraft weapon which was too slow or had too low a ceiling was assigned it was an "undermatch" and would always miss (cf. also Appendix I). It was also possible for the commanders to make one-class and two-class overmatches, i.e., assigning fighters of a class appropriate to threats one or two categories higher than the threat in question in speed and/or altitude. There was also the possibility that a previous assignment by the commander had already effected a kill or would effect one prior to the time that the assignment in question could do so. Lastly, there were two categories of untimely assignment -- the "tail-chase" wherein the target had turned back and was running away before the weapon could be scrambled and the "too late" wherein the target was already so far away that it could not be intercepted in the time available or within the surveillance area.

The overall kill rates did not differ from tape to tape except in one instance. Table 4 gives a summary of the percentages of threats killed classified by load and tape. Except at load 60 there are only very small differences between tapes in the kill rate. The definite difference at load 60 in favor of the Tape II results is a function of a slightly higher average number of kills per run (1.7 more per run) and

TABLE 4

Percentage of Threats Killed

	Load			
	60	72	84	96
Tape I	79.5	82.9	77.7	70.2
Tape II	86.7	83.6	77.5	70.4

a slightly lower average number of threats per run (2.8 less). This was an accident of the construction of the tapes and the selection of blocks of tracks used to make up the load 60 problems. Although there were only six non-hostile tracks in either tape, those in Tape II appeared more frequently in the load 60 problems. Note the general trend to decreasing percentage of kills as load is increased. The number of kills (cf. Figure 3 above) actually rises with load but at a decreasing rate, as witnessed by the sharp drop in percentage kills between load 84 and load 96.

When the threat tracks were divided into those programmed to penetrate (and inflict damage) and those not so programmed, there is no large or systematic difference between the two classes. Table 5 presents a summary of the percentages of "real" (potential damage) and "apparent" (no potential damage) threats which were acted against

TABLE 5

Percentages of "Real" vs. "Apparent" Threats
Assigned Against and Killed*

Tape		Load 60	Load 72	Load 84	Load 96
I	Real	83	88	86	81
	Apparent	91	91	88	76
II	Real	92	92	91	90
	Apparent	93	93	89	85

*(# killed ÷ # assigned against) X 100

and killed. It must be remembered that not all threats (of either class) were acted against in either tape so that the kill percentages here are all higher than those found in Table 4 for the same loads. Except for load 60 in Tape I and load 96 in both tapes the differences between real and apparent threat kill rates are quite small. In Tape I a higher percentage of apparent threats was killed except at the highest load while in Tape II the same is true at the lowest loads and the reverse is true at the higher loads. The generally lower kill figures for Tape I as compared to Tape II are accounted for by two factors - the relative numbers of threats acted against and the numbers of weapons assigned. In general, in the Tape I problems, a somewhat smaller number of assignments and re-assignments was spread over a somewhat greater number of threats acted against. This was the choice of the commanders, since the numbers and kinds of threats were equivalent in the two tapes (with the minor exception in Tape II load 60 already noted).

The really important point here is that "real" and "apparent" threats were acted against almost indiscriminately. As was noted above, commanders tended to ignore fighter-type threats or to withhold action against them until the more potent vehicles had been acted upon. They did not, as has just been shown, either learn to recognize (through having seen some of the tracks before in other loads) or single out for special attention (due to the apparent heading of the threat or other data available to them) those tracks which would actually cause damage if not killed. The general tendency of the commanders to concentrate - in number, size and potency of assignments - on bombers first, then on fighter-bombers and lastly on fighter-type threats is indicated further by the general kill-to-miss ratios shown in Table 6. If the first three assignments against tracks are considered (these would include over 90% of all assignments) it may be seen that nearly two out of three assignments against bombers were successful. Table 6 presents the ratios of numbers of assignments resulting in kills to those resulting in misses for the three general classes of aircraft threats by load and tape. The variability induced by load is neither great nor consistent. It should be noted, however, that the ratios for bomber type threats are the highest (i.e., more of the assignments against bombers were successful) and those for fighters are the lowest. The small but apparently

TABLE 6

Ratio of Assignments Resulting in Kills to Those Resulting in Missed Intercepts

		Load				
		60	72	84	96	All
Bombers	Tape I	1.6	1.2	1.8	1.4	1.52*
	Tape II	1.9	1.9	1.5	1.7	1.76
Fighter Bombers	Tape I	1.0	.9	1.0	.9	.98
	Tape II	.9	1.1	.9	.7	.94
Fighters	Tape I	.8	.8	.8	1.1	.87
	Tape II	.9	1.0	.8	.7	.90

* Slight difference between average over all loads and average of individual averages are due to rounding errors.

reliable difference in favor of the Tape II assignments against bombers helps to illuminate the explanation previously advanced for the superior damage prevention ("down-time") in the Tape II problems. In general, a higher kill-to-miss ratio would result from the use of more weapons in the assignments or higher capability weapons or both.

Before leaving the subject of kills and misses it should also be noted that the ground-to-ground and air-to-ground IRBM threats were very well countered by the commanders (and caused comparatively little damage). However, these threats also were acted against without much discrimination in the "real vs. apparent" threat sense noted above for aircraft. The assignments against them succeeded in ratios of nearly four to one. As will be seen below, this type of threat was acted against very quickly. In addition, the anti-missile counter weapons were extremely lethal. These two factors tended to result in high proportions of kills.

In summary of the overall outcome data it may be said that the threat evaluative activities of the commanders, as inferred from these results, were of a rudimentary sort. In the absence of other information on which to base relative or absolute evaluations of threat the commanders acted primarily upon the identified object class. While some (comparatively poor) information as to heading was to be had from persistence trails the main items of situation data available were position, speed and altitude. Unless some pre-evaluation or weighted combination of these and/or other relevant factors were to be supplied to the commanders, it could be predicted that their actions would be based upon broad criteria weighed only crudely and selected under the pressures of load and time.

When other categories of outcome are considered some interesting features emerge. Table 7 contains a summary of the average numbers of the six different categories defined above which were found per run as a function of load. Since differences between tapes here were neither large nor consistent, Table 7 contains averages through both tapes. The single-class overmatch was more frequent than the two-class overmatch at all loads. The unusually high numbers of overmatches at load 84 were most likely due to temporary

TABLE 7

Average Number per Problem Run of Outcomes
Other than Kill or Miss

Outcome	Load 60	72	84	96
Single-class overmatch	1.1	1.3	3.0	1.4
Two-class overmatch	.8	.9	1.6	1.2
Previously killed	12.1	6.4	5.5	4.0
Undermatch	1.2	1.6	1.8	1.9
Tail-chase	.4	.4	.4	.6
Too-late	1.5	1.0	2.2	2.4

unavailabilities of lower performance weapons (e.g., Red and Blue class aircraft - cf. Appendix I) caused by base closure as a result of hostile penetration. The small total numbers of overmatches and undermatches overall, however, are definite indications that the commanders were taking care in the application of matching criteria -- selecting weapons which had the appropriate speed and altitude capabilities and neither "wasting" high capability weapons on lower capability threats nor failing to kill by assigning weapons without the performance necessary to intercept. While this matching behavior tends to deteriorate as a function of increased load it does not do so seriously. It may be noted also that the higher loads produced somewhat more untimely (Tail-chase or Too-late) assignments. More attention will be given to this question below under "Delay Times."

The largest single category of outcome to be seen in Table 7 is that of "previously killed." These were "unnecessary" assignments. Most frequently they consisted of the assignment of ground-to-air missile counter weapons against targets to which previous assignments of aircraft had been made. If the outcome of the earlier assignment had not yet become known to the commander and if the target was still present a back-up or additional assignment was made fairly frequently. Such occurrences were more frequent at the lower loads, where the inventory appeared more ample and where the pressure of load permitted additional assignments. Even here, however, where the commanders were indeed somewhat "wasteful" of their weapons such assignments only constituted a fairly small proportion of all assignments except at the lowest load. It may be inferred that, when a substantial superfluity of weapons appears to exist, the human decision maker tends to let considerations of damage prevention and destruction of enemy forces override considerations of economy of weapons.

<u>Action Kill Probabilities:</u>

The kill probability of any action selected is, in a certain sense, an overall evaluation of its quality. True, it reflects the quality of other factors besides the choice itself in "real life", including the capability of the weapon selected, the quality of the intercept direction, etc. In this experiment, however, these other factors were not allowed to affect the probability of kill. It was (as may be seen in considerable detail in Appendices I and III) strictly determined by the kind, the number and the armament of weapons chosen by the commander and the <u>time</u> at which the action was selected. In this study, therefore, the kill probabilities of selected actions reflect the quality of the choice made by the commanders. Table 8 contains a summary

TABLE 8

Percentage of Actions and Average Kill Probability as Functions of Assignment Mode

	Load							
	60		72		84		96	
Action Mode	%	P_r	%*	P_r	%	P_r	%*	P_r
Single Flight	66	.51	64	.50	65	.49	63	.50
Two-at-Trail	22	.57	24	.59	23	.58	23	.58
Three-at-Trail	12	.63	13	.66	12	.66	13	.64

*Failure to total 100% is due to rounding errors.

of the proportions of the three major classes of assignment made and the average kill probabilities which they involved. Both tapes are averaged here since there were no consistent or large differences between tapes. The major point of interest in Table 8 is the remarkable consistency in both mode of assignment, and average action quality (as indicated by the kill probabilities) from load to load. About two-thirds of all actions selected were in the "single flight" mode. These were most frequently of the "single weapon against single threat" type, although some consisted of two or even three weapons. The latter was more frequently true in the case of missile counter weapons. The reason for this type of assignment being the most frequent is that it was the only permissable mode for missile assignment and it was the most economical mode for aircraft assignment (cf. also Appendices I and III). That is, if two or three aircraft were to be used in a single assignment it was advantageous to assign them "at trail" since an improved probability of kill was insured thereby (cf. Appendix III on "Referee Sheets"). Note, however, that the average kill probability of these "single flight" assignments was the lowest, averaging .50 overall.

Assignments of aircraft counter-weapons "two at trail" were next most frequent (just under one-quarter of all assignments) followed by "three at trail" which constituted about one-eighth of the assignments. There is, as might be expected due to compounding of probabilities in trail assignments, a rise in average kill probability to .58 for two at trail actions and further to .65 for three at trail actions.

As noted above, the important point here is the consistency of the commanders. The general tenor of their assignments was not affected by load either in kind or in overall quality. The major effect of load, as has been pointed out above, was on the number of assignments and the major effect of the difference between tapes was on the kinds and numbers of threats against which actions were taken. The only evidence for adaptation of assignment kind to conditions appeared in replications 3 and 4 of load 60, both tapes, wherein the commanders made more "three at trail" assignments (18%) and less "two at trail" (13%) than under other conditions. This reversal is most likely in some way due to the requirement in these replications that threats be acted against only track-by-track and not as raids. The prohibition of raid-type actions eliminated the inherent advantage of such actions (the ability to obtain the same kill probability against two tracks as against one with the same number and kind of weapons, cf. Appendix I) and evidently induced the use of more three at trail assignments in compensation. The point is that load alone did not affect the kind of action selected by the commanders. It would be interesting to discover the manner in which this pattern might have changed if other factors were varied (such as kinds and number of weapons available) since the elimination of raid-type assignments appeared here to have had some effects.

Assignment Delays:

The last performance measure which will be discussed is that of delay in assignment. This was defined as the time elapsed between the initial appearance of a threat and the time an action was assigned against it. Table 9 contains a summary of the delay time data including both "tapes" and all replications. The difference between "tapes"

TABLE 9

Average and Variability of Delay in First Assignment (Minutes)

	Load							
	60		72		84		96	
	Mdn	Q	Mdn	Q	Mdn	Q	Mdn	Q
Single Assignments:								
IRBM's	.6	.3-.9	.4	.2-.7	.6	.4-1.1	.6	.3-[illegible]6
Bombers	.8	.5-2.4	.7	.3-2.2	1.0	.5-3.2	.9	.6-2.1
Fighter Bombers	.7	.4-1.2	.8	.5-1.3	.9	.5-2.5	.9	.6-1.8
Fighters	.7	.4-2.0	.7	.4-2.1	.9	.5-1.8	.9	.5-1.8
Raid Assignments:								
Bombers	.6	.5-.9	.5	.3-.7	.7	.5-1.0	.6	.4-1.2
Fighter Bombers	.6	0-1.1	.7	.5-1.0	.8	.7-1.2	.9	.6-1.5

and replications were neither large nor consistent. The upper section of the table presents the median (mdn) delay times and the ranges within which the middle 50% of delays fell (Q) for tracks assigned against one-by-one. The lower section of the table gives similar data for tracks assigned against in multiple or "raid" assignments.

The two most noticeable features of the delay times are that, for tracks acted against singly, the quickest "reactions" were found for IRBM threats and that reactions to bombers and fighter-bombers in raids were generally faster than when handled singly. It is evident that the commanders were taking account of two factors here. In the case of the missile-type threats time was recognized to be of the essence. Rapid action was important because of the speeds of these targets - initial assignments had to be made quickly and they were. The variability in reaction time was smaller for this class of target than for any other when handled one at a time. In the case of tracks in raids the raids apparently were perceived as more threatening than single tracks and in addition offered the commanders the opportunity to act against several tracks simultaneously and thus reduce their task burden.

Except for the IRBM's, there are no large or consistent differences in time delay amongst the categories of threats when acted upon singly. Average delays are all small and, in general, shorter than those found in the previous experiment (4) where the same commanders were employed. Much of this improvement is probably due to the raid assignment method which helped reduce the backlog of tracks to be acted upon in rapid fashion. It should be pointed out that there is a trend toward increasing reaction time with increased load as might be expected. Variability was not greatly affected by load in the single assignments but appeared to increase slightly at higher loads for the raid assignment. The tendency to concentrate on bombers prior to other categories of aircraft threats which has been remarked previously is evident in the shorter delays (in most cases) found for bombers as opposed to fighter-bombers when handled in raids.

The conclusion to be drawn from these data (as from some of the other measures) is that the commanders tended to react to and act upon broad classes of threats in a fairly consistent and characteristic manner. They were too pressed by the overall task to try to make fine, individual evaluations or discriminations. The actions they selected and the general principles of action that they adopted were appropriate and effective.

CONCLUSIONS AND RECOMMENDATIONS

There was some evidence in the results of this study that the general level of performance of tracks in the surveillance situation, particularly their speeds, influenced the actions of the commanders in a general way. Against Tape II threats (higher average speed) the commanders exhibited a different sort of selectivity amongst threats. While fighter-type threats were often ignored completely or action against them was deferred in both tapes, there was a tendency for less actions against fighters in Tape II situations. In addition, the commanders tended to concentrate somewhat more on bomber-type threats in the higher performance situations. This general shift in tactics, while partly explainable in terms of experience effects cannot be completely accounted for thereby. While fine discriminations between threats apparently were not being made, the commanders showed a highly developed ability to make correct and appropriate "matches" to targets in their selection of counter weapons. It is likely that if better or more explicit indications of heading had existed in the position situation display, the commanders would have made more detailed discriminations and somewhat fewer general ones (e.g., as between "this bomber vs that bomber" rather than "bomber vs fighter-bomber").

Another finding (though not startingly new) was that pressure of a backlog of tasks "pushed" the commander toward what appears to be a "natural" limit in their capacity to make the kind of decisions required in this study. This limit seems to be fairly stable at a level of five to six per minute. Even where they were pressing this limit, however, the overall quality of the actions selected (as indicated by inclusive measures such as kill probability) did not deteriorate seriously. Thus, while increasing task load tended to increase delays in the selection of counter actions, the increase in "reaction time" was not serious enough to degrade the effectiveness of the average action.

The effects upon decision making performance in this study of the quality of surveillance data were neither very great nor sharply defined. However, the lowest quality tracks did appear to be handled somewhat differently than those whose data were more correct and complete. Very low quality tracks attracted the use of less weapons generally. Undoubtedly some of this effect is due to a fairly obvious factor - if you don't see it as often or as long, you will not attend to it. In addition to this effect, however, there was evidence that low quality tracks attracted a different kind of reassignment. Low quality tracks were reattacked with the use of aircraft counter weapons much more frequently than were the better tracks (where missiles were used most frequently). While there may have been other logic behind such a tactic it is likely that commanders were reluctant to use their non-recallable weapons against doubtful tracks. In any case, tracks whose data were fifty per cent or more complete and correct were handled in essentially the same manner as those whose data were perfect. The commanders had neither the time nor the specific information necessary to thus differentiate on any explicit basis - it was done through some ingrained, implicit process.

Finally, it was found that economic considerations tend to be overlooked. Despite the fact that the matching of weapons to threats was very good not much care was taken to conserve weapons. There was a definite tendency on the part of the commanders to "use up" available weapons and even squander them somewhat when the supply appeared to be much greater than the "demand". This is probably perfectly natural in view of their really primary concern - to avoid damage and to decimate the forces of the enemy. In practice, however, it is probably not good strategy.

From these results, several recommendations may be evolved.

1. Man-machine surveillance systems should (as most now do) provide reasonable indications of heading of targets to human evaluators.

2. At least some gross indications of the reliability of surveillance data should be provided to commanders.

3. The capabilities of commanders in monitoring and overriding an automated or semi-automated decision making system should be investigated in detail.

4. Decision criteria for man-machine decision makers should be developed to include economic and logistic considerations even at the direct action or battle level.

5. Large amounts of intensive experience in reasonably realistic conditions and under high task loads should be provided for commanders at all levels. Such experience not only promotes maximum performance, but may prevent overload from producing drastic effects.

6. The effects of different kinds and degrees of "pre-digestion" or synthesis of surveillance data on decision making performance should be investigated.

APPENDIX I

Instructions to the Commanders:

The general mission of the commander or decision maker in this experiment will be essentially the same as in previous experiments. This mission is threefold:

1. To minimize damage to defended areas,
2. To destroy a maximum number of threatening vehicles,
3. To conserve counter weapons so as to consume a minimum of defensive forces consistent with objectives (1) and (2) above.

The specific tasks by which controllers may accomplish these objectives will be quite similar to those employed in previous experiments. The purpose of this briefing brochure is to outline some of the specific differences in procedures which will be required for the present experiment.

A. Threat Vehicle Types

In the present experiment there will be four broad categories of threatening vehicles. There will be:

1. IRBM Type Missiles. These may be of the land-launched (therefore first appearing at the edges of the coverage area and at speeds of 3000 knots) or air launched (and thus first appearing further within the coverage area and at speeds of 2000 knots). These will be distinguished primarily by extremely high speed. "Decoys" may be present. This type of threat may be countered only by an inventory of anti-missile missiles of long range, high speed and high capability.

2. Air-Breathing Bomber Threats. There will be four broad performance categories within this class:

(a) Ultra-high Bombers - This group includes bombers of very high speed (1500 knots) as well as altitude (90,000 feet). These may be countered only with ground-to-air missiles and with White-class fighters.

(b) High Bombers - This group includes bombers of lower altitude (75,000 feet), but which may vary in speed between 1000 and 1500 knots. The "matching" class fighter is the Green-type. Missiles, of course, may also be used. In the event that such a threat is "over-matched" (by countering with White-class fighters) the intercept will be timed at Green-class speeds and altitudes, but taking into consideration the higher kill capabilities of the White-class weapons.

(c) Medium Bombers - This group of vehicles includes bombers whose altitude is lower still (60,000 feet) but whose speed range overlaps with that of the High bomber types (800-1200 knots). The "matching" class of interceptors is the Blue-type. As noted above, any overmatch will be run at Blue-class speeds, but will be given the advantage of the higher class kill probabilities. Again, all types of ground-to-air missiles may also be used against this type of threat.

(d) Low Bombers - These vehicles have an altitude capability of 50,000 feet and speeds of the order of 800 knots. The "matching" class is the Red-type. Overmatches will be handled as mentioned above. Ground-to-air missiles may be used.

3. Fighter Bombers. There are three classes of fighter-bombers:

(a) High - Altitude 55,000 feet, speed 600-800 knots. The matching class fighters are the Red IR and Blue-types.

(b) Medium - Altitude 30-45,000 feet, speed 5-600 knots. Red-type fighters are the matching class.

(c) Low - Altitude 50,000 feet, speed 600 knots. Red-type fighters are the matching class. (Note: There was also one very low altitude fighter-bomber raid at 5,000 feet about which the commanders were not forewarned). Ground-to-air missiles may be used against all types of fighter-bombers. Overmatches will be handled as noted above under "Bombers".

4. Fighters. Threatening fighters will be of four classes:

(a) Ultra-High - 90,000 feet, 12-1500 knots
White fighters are the matching class.

(b) High - 75,000 feet, 10-1200 knots
Green fighters are the matching class.

(c) Medium - 60,000 feet, 8-1200 knots
Blue fighters are the matching class.

(d) Low - 30-50,000 feet, 600 knots
Red fighters are the matching class.

The general characteristics of the threat vehicles which have been listed above, while generally definitive, will not be absolutely iron-clad. There may be some threats at very low altitude and comparatively high speed. In addition, the auxiliary data associated with a track will be subject to error (see section on "Intelligence", below).

B. Counter Weapon Types and Sites

The counter weapons available to the controller will be of three broad types. They will be located at ten sites, two such sites in each of five larger defended areas. The forward or enemy-ward areas will be designated areas 1 and 2. The intermediate areas some distance directly behind the latter will be designated areas 3 and 4. The single rear area will be designated area 5. All counter weapons (except Red class aircraft) may have either high yield or low yield armament. The long range missiles with high yield warheads will have a ten mile blast radius. High yield aircraft and high yield short range missiles will have five mile blast radius. Low yield weapons are of the contact type. The general weapon classes will be:

1. Anti-Missile Missiles. These weapons are of high speed (3000 knots) and high accuracy and are armed with high yield warheads giving them a very high kill probability. They will be located in area 5, the rearward area. They will be housed in hardened fashion, some ready to fire and some in standby and will be relatively impervious to all except high yield direct hits. They will be found in silo-type shelters. "Standby" missiles require three minutes to be converted to "ready" status. While this will be taken care of automatically it should be remembered that rapid consumption of ready missiles could result in delay in firing due to transition from "standby" to "ready".

2. Other Ground-to-Air Missiles.

(a) Long Range Missiles - These weapons are of two types - high yield warhead and low yield warhead armed. They will be found in hardened and semi-hardened bases located in areas 3 and

4. They are capable of kill anywhere within the coverage area against any type of target except IRBM's. The high yield types, of course, have higher kill probabilities.

(b) Mobile Missiles - These weapons have similar characteristics and capabilities to the Long Range type except for lower kill probabilities and that they will be found on mobile launchers in the forward areas 1 and 2 and may be, therefore, somewhat more vulnerable to attack than other Long Range Types. Their "mobility" is more a matter of definition here than a matter for concern or manipulation on the part of the decision maker.

(c) Short Range Missiles - These weapons have a maximum range of 100 miles and will be located at sites in areas 3 and 4 in such a way that their coverages overlap and also span the width of the surveillance area. They will be of both high and low yield armament types and will be of somewhat lower capability generally than the Long Range missiles. They will be found in both semi-hardened and "soft" configurations.

3. Interceptor Aircraft.

(a) White Class Fighters (90,000 feet) - These are a very high performance, very high capability interceptor some of which will carry higher yield armament than others (resulting in a higher kill probability). As noted above they are the matching class counter weapon for ultra-high performance threats. They will be found in area 5 only. White fighters may not be used against targets below 70,000 feet.

(b) Green Class Fighters (75,000 feet) - These are a high performance interceptor, some of which will have high yield armament. They will be located at bases in areas 3 and 4.

(c) Blue Class Fighters (60,000 feet) - These are medium performance weapons and may be high or low yield armed. They will be based in both areas 3 and 4.

Note: White, Green, and Blue class fighters will be found in both "hard" and "soft" configurations. The hardening will be of the "cave" or "tunnel" type and there may be some degree of delay in the launching of hardened aircraft.

(d) Red Class Fighters - These are low performance weapons. They may be armed with either IR seeker missiles (usable to 55,000 feet) or with guns (49,000 feet). In general, they are the matching class weapon for low performance threats. However, there is one exception. The missile-armed Red fighters may use the "snap-up" attack. Infra-red seeker armed fighters of this class, therefore, may be employed against threatening vehicles which are either above the altitude capability of the Red fighters (i.e., up to 55,000 feet) or above the speed capability of Red fighters (max. 600 knots), but not both. That is, Red fighters may be employed against some high and medium class threats except where the threat is above both 50,000 feet and 600 knots. Gun-armed Red fighters may only be used against low performance threats.

C. Scoring Procedures

In general, where "matching" class fighters or ground-to-air missiles are assigned by the controller, scoring will present no problems. An "undermatch" (assignment of a Blue class weapon to a threat for which the matching class is White, for example) will be scored as a miss. Overmatching, as described above will ordinarily increase kill probability but will give no advantage in intercept time (or return-to-inventory time).

D. Weapon Assignment Modes and Procedures

One of the most important points to be remembered concerning weapon assignments, aside from selection of appropriate weapons, will be the standardization of the assignment message format. Standardization in this respect is of the utmost importance from the experimental and from the practical operational point of view. Experimentally, only standard messages can be handled with the required speed and accuracy by the clerks and referees. However convenient a non-standard message is to the controller, it shows down or confuses the execution of the assignment resulting, ultimately in penalty to the controller. In addition, future systems will require communication with machines in language the machines can understand. Non-standard messages are understood and executed even less well (i.e., not at all) by machines than by men (as in the present experiment). Therefore, an essential part of procedure will be the use of rigid message formats. The assignment message will consist of the track number assigned against, the weapon kind to be used, the site to be drawn from, its armament category and the number to be used (e.g., Track 84, "Green three high two").

As in previous experiments, weapons may be assigned one, two or three at a time against individual threats. In addition, "trail" type assignments of two or three successive aircraft may be used. Due to the actual vagaries of surveillance data and close control performance (i.e., a prior failure of control might still add data to improve a subsequent attempt), trail type assignments generally result in a higher kill probability overall. Weapons not actually employed will be returned to inventory as before.

In this experiment there will be groups of threats in the form of "raids". The number of individual tracks in a raid may vary from two to ten or more. Raids will appear strung out across a "front", individual tracks five to ten miles apart. Tracks in a raid will bear the same "personal identification" and a raid size indication will appear at the right-hand end of the auxiliary data readout panel. Zero here indicates "unknown" raid size (10 or more tracks), one indicates "small" (2-3 tracks), two indicates "medium" (4-6 tracks) and three indicates "large" (7-9 tracks).

Raids may be countered by making single assignments between pairs of tracks in a raid with high-yield missiles or high yield armament aircraft. Such assignments will result in the same liklihood of killing both members of a pair as if two separate assignments had been made, one to each individual track. In making such assignments a track number from the counterclockwise end of the raid front and the raid designator (e.g., B-2) should be given to the scramble clerk, followed by the weapon type, weapon site, armament and total number of weapons to be used against the raid as well as the manner in which it is desired that weapons be used (e.g., single weapons between tracks, two at trail between tracks, etc.). Raid traffic may also be handled track by track individually. Long range missile fire may be accomplished on a 1/1, 2/1, or 3/1 salvo basis, with successive salvos not permitted until after intercept outcome data is fed back. Short Range Missiles may be assigned for successive "salvo" firing in numbers not to exceed 3 per salvo. They will be fired one minute apart. Probably, however, all missiles so assigned will be removed from inventory at time of assignment. Unfired missiles will be returned to inventory.

Kill probabilities for White type aircraft will vary from .3 to .8, depending on number assigned, armament type and delay in assignment as before. Green class fighters will have kill probabilities of .2 to .7, Blue class .1 to .6, and Red class .1 to .5. The more weapons assigned (up to 3, either together or in "trail"), the higher the potency of the armament and the sooner after onset of the threat the higher the probability of kill.

Short range missiles may be fired on specific assignment or may be ordered to fire autonomously at specific track numbers as they come into range (100 miles) of the site selected. When such an autonomous fire is ordered it will be done automatically by the experimenters.

Areas 1 and 2 are located in the forward region and are not hardened. They are therefore comparatively vulnerable to damage.

Their weapons should be used early and the bases may be sacrificed or evacuated in advance of and in favor of protecting rearward areas.

Bases may be evacuated (i.e., aircraft scrambled to air-borne status) not more than one at a time. Lost fighter probabilities will be applied to all evacuated fighters. Weapons may not be evacuated at a rate of more than three per minute. Weapons may be ordered from a state of "soft" readiness into hardened shelters at the same rate.

E. Intelligence

1. Certain classes of threats will be more likely high yield carriers than others.

(a) 50% of IRBM threats will be high yield carriers

(b) 35% of ultra-high and high level bombers

(c) 15% of medium level bombers

(d) 10% of low level bombers

(e) 25% of fighter bombers will carry high yield weapons.

2. Decoys may be present to the extent of:

(a) 50% of IRBM's and

(b) 10% of high level bombers.

3. Countermeasures may be expected. These will tend to jam sensors, communications, weapon direction and homing systems. This will result in stopping, fading and jumping of track position data and some scrambling of auxiliary data. When in doubt as to the quality of track data or apparent contradiction or change of ancillary data the controller may inquire and will be informed of the quality of the data available on any given track (in broad categories from "very poor" to "excellent").

APPENDIX II

SECTION 1

Track Situation Recordings:

1. Two basic tape recordings of track situations and auxiliary data were prepared. Each tape contained 96 complete tracks (except as noted below) in "blocks" of 12 targets. The data for each track consisted of its life history of positions (i.e., its flight path) and the identifying or descriptive auxiliary information connected with it (i.e., IFF, type, speed, altitude, raid number if any, and raid size if any). The proportions of tracks of different types will be found listed below. Descriptions of their detailed characteristics may be found in Appendix I.

2. Each block of 12 tracks could be selected for display or completely suppressed. This permitted the number of tracks presented in a problem situation to be "solved" by the commander to be varied from 12 to 96 in multiples of twelve. Track numbers were scrambled in systematic fashion so that there was no discernible order which would tend to relate any track to others.

3. There were 36 tracks (three blocks) which were common to both tapes. That is, these identical tracks in all respects appeared in both tapes.

4. The remaining tracks were programmed to have different general characteristics in each tape. The 60 tracks which were specific to Tape I were mainly air-breathing threats within a speed range of 800 to 1200 knots and an altitude range of 50 to 75 thousand

feet plus a small number of IRBM's in the 3000 knot class. Tape II tracks included some air-breathers with speeds up to 1500 knots and altitudes up to 90,000 feet plus IRBM's as before. The average speeds of each performance class were higher in Tape II.

5. The track paths were drawn up on paper to meet the pre-selected specifications of the experimental conditions and, using target generators and associated equipment (2, 5) were recorded on magnetic tape. This insured almost absolute duplicability of the "stimulus" material from time to time and from subject so subject. Different combinations of blocks were displayed for different total loads and for the same loads when presented on different occasions. Experience has shown, that under the circumstances of these experiments, little or no specific learning of the stimulus situation takes place.

6. In both tapes pre-programmed degrees of data reliability were applied to each track. Both tapes contained equal proportions of tracks, the data on which were 10%, 20%, etc., "reliable" (complete and correct) in ten per cent steps to 100 per cent. The unreliability introduced was of two kinds. One type was in track position data wherein tracks disappeared or stood still for the appropriate proportions of their track lives. Approximately three-fourths of the unreliability was of this type. The second type of unreliability was introduced into auxiliary track data as erroneous or missing identification, speed or altitude. Blocks of tracks were approximately balanced for the total amount of uncertainty so that the average data quality in any single problem was of the order of 66% complete and correct, with a range of 62 to 67 per cent.

7. Constitution of the Situation Tapes by Threat Kind:

Kind	Performance	Number Tape I	Tape II
IRBM's	"Real"	2	4
	"Decoy"	4	2
Bombers	Ultra-High	0	6
	High	12	10
	Medium	12	10
	Low	12	10
Fighter-Bombers	High	12	6
	Medium	6	12
	Low	6	6
Fighters	Ultra-High	0	6
	High	8	6
	Medium	8	6
	Low	8	6
Friends		6	6

8. Constitution of Situation Tapes by Data Certainty Rate:

% Data Complete & Correct	Number of Tracks Tape I	Tape II
10	4	4
20	5	5
30	5	5
40	7	7
50	11	11
60	11	11
70	12	12
80	13	13
90	13	13
100	15	15

Distribution of these tracks was approximately balanced over threat kinds and through blocks of tracks so as to make it possible to construct complete problems of various total loads of very similar characteristics in these respects.

9. Fifty per cent of the hostile tracks in both tapes (nearly all tracks were, in fact, hostile or potentially hostile (i.e., unknown) were programmed to inflict damage if allowed to penetrate the defended areas. Possible damage ranged from the loss of one defensive weapon to total destruction of the weapon site. In addition, damage could effect the closing of a site (no weapons could be scrambled from that site) for periods ranging from three minutes to indefinitely. If all tracks capable of inflicting damage were allowed to penetrate 100%

damage (i.e., total loss of all defensive weapons) would have ensued. This last was true at all loads (60-96 tracks) used for data purposes.

SECTION 2

Experimental Design:

The "design" of the present experiment was not of any complete classical sort. Such would have been most impractical in terms of the magnitude of effort required and did not seem to be necessary to the aims of the program. The variables were:

1. Track Situation Load. For data purposes there were four such: 60, 72, 84, and 96 total tracks appearing over a 45 minute period. In all cases about one-third of the total were present by the end of the first five minutes and 90% had entered by problem time 25 minutes.

2. Operating Performance Range of Threats. This variable was defined by the two tape recorded track situations described above. Tape I included threats of a more restricted speed and altitude performance than those in Tape II. The object here was to ascertain the effects, of a faster vs a slower moving and developing situation on the performance measures selected.

3. Data Quality. This was a variable which was internal to all other combinations of conditions and approximately equally weighted in each combination so that it would not have undue differential effects on any one or another combination of "tape" and "load".

A fourth variable might be considered to be that of "Commanders" or "Subjects". However, the data for all subjects were combined in treatment and this variable was not examined separately.

Attempts were made to control learning effects by counter-balancing and/or mixing of the order of presentation of conditions within each subject. Attempts were made to insure reliability by replication of most combinations of conditions. Each commander (except one) faced various combinations of 60 track loads from each tape four times. Each commander faced two different combinations of 72 and 84 track loads from each tape. Since there was only one combination of 96 tracks in each tape, this load was not replicated.

On the first two replications of 60 tracks, commanders were permitted to employ "raid" assignments (cf. Appendix I) but on the last two replications only track-by-track assignments were permitted.

APPENDIX III

SECTION 1

Weapon Inventory and Status Board:

Figure 1 is a drawing of the weapon status board as it appeared at the beginning of every problem run. The names (Red, Blue, Mobile, Long, etc.) refer to the classes of weapons available to the decision maker. The numbers outside the blocks (on either side of the weapon kind name) refer to the sites at which such weapons were available. The lettering across the tops of the larger subdivided blocks refer to the state of readiness. For aircraft (color names left hand side of board) these were RH meaning "Ready in Hardened Hangars", RS for "Ready in Soft Locations", AA for "Available (already) Airborne", and SY for "Standby" (to become available after some delay). The letters H, S, and SY on the missile side of the board stand for "Hard", "Soft" and "Standby" with the same meanings. The letters defining rows stand for the type of armament carried by the weapons, IR for infrared seeker rockets, G for guns, H for high-yield blast armament, L for low-yield armament. The numbers in the boxes refer to the quantities of the specified weapons available at the start of the problem. These were adjusted by status board keepers as assignments were executed and weapons were utilized.

Weapons were scrambled from "Soft" storage until exhausted then from hardened storage. Commanders were required to so state specifically when they desired to divert airborne available fighters. Returning fighters were placed in standby for standard intervals, then placed in a ready status.

Figure 1.

Weapon Status Board (Time 00)

RED

1

	RS	AA	SY
IR	14		
G	6		

2

	RS	AA	SY
	14		
	6		

MOBILE

1

	S	SY
H	3	1
L	9	3

2

	S	SY
H	3	1
L	9	3

BLUE

3

	RH	RS	AA	SY
H	3	7		
L	1	9		

4

	RH	RS	AA	SY
H	3	7		
L	1	9		

LONG

3

	H	S	SY
H	4		3
L	7	1	1

4

	H	S	SY
H	4		3
L	7	1	1

GREEN

3

	RH	RS	AA	SY
H	5	5		
L	2	8		

4

	RH	RS	AA	SY
H	5	5		
L	2	8		

SHORT

3

	H	S	SY
H	5	1	1
L	5	5	3

4

	H	S	SY
H	5	1	1
L	5	5	3

WHITE 5

	RH	RS	AA	SY
H	10	5		
L		5		

ANTI. M.

RH	SY
6	4

SECTION 2

Referee Sheets:

Figures 2 and 3 are samples of the referee outcome evaluation forms which were used in this experiment. Figure 2 is an aircraft counter-weapon referee sheet and Figure 3 a missile referee sheet, both for the same specific track. Entries are explained as follows for Figure 3:

1. Upper right corner:

B1 50/800 (24-29-34-45) 04.

B1 stands for low performance hostile bomber.

50/800 stands for an altitude of 50 thousand feet, speed of 800 knots.

24-29-34-45 stands for the onset time of the track and the ends of the three critical time periods during its life, i.e., its first and second five minute periods and its time of disappearance (unless previously killed).

04 is the identifying number of the track.

2. Upper right corner:

80-87-94-04-11-73 stand for the numbers of all tracks in the raid of which this track was a part reading clockwise along the raid front as they appeared in the situation display.

3. Left side:

4 (12-9-7) stands for site 4 and the times taken to intercept (or fail to intercept) as a function of the time period during the life of the track during which the assignment was made. As an example, if an assignment of Blue type aircraft was made against track 04

Figure 2. Sample Aircraft Referee Sheet

B1 50/800 (24-29-34-45) 04
80-87-94-04-11-73

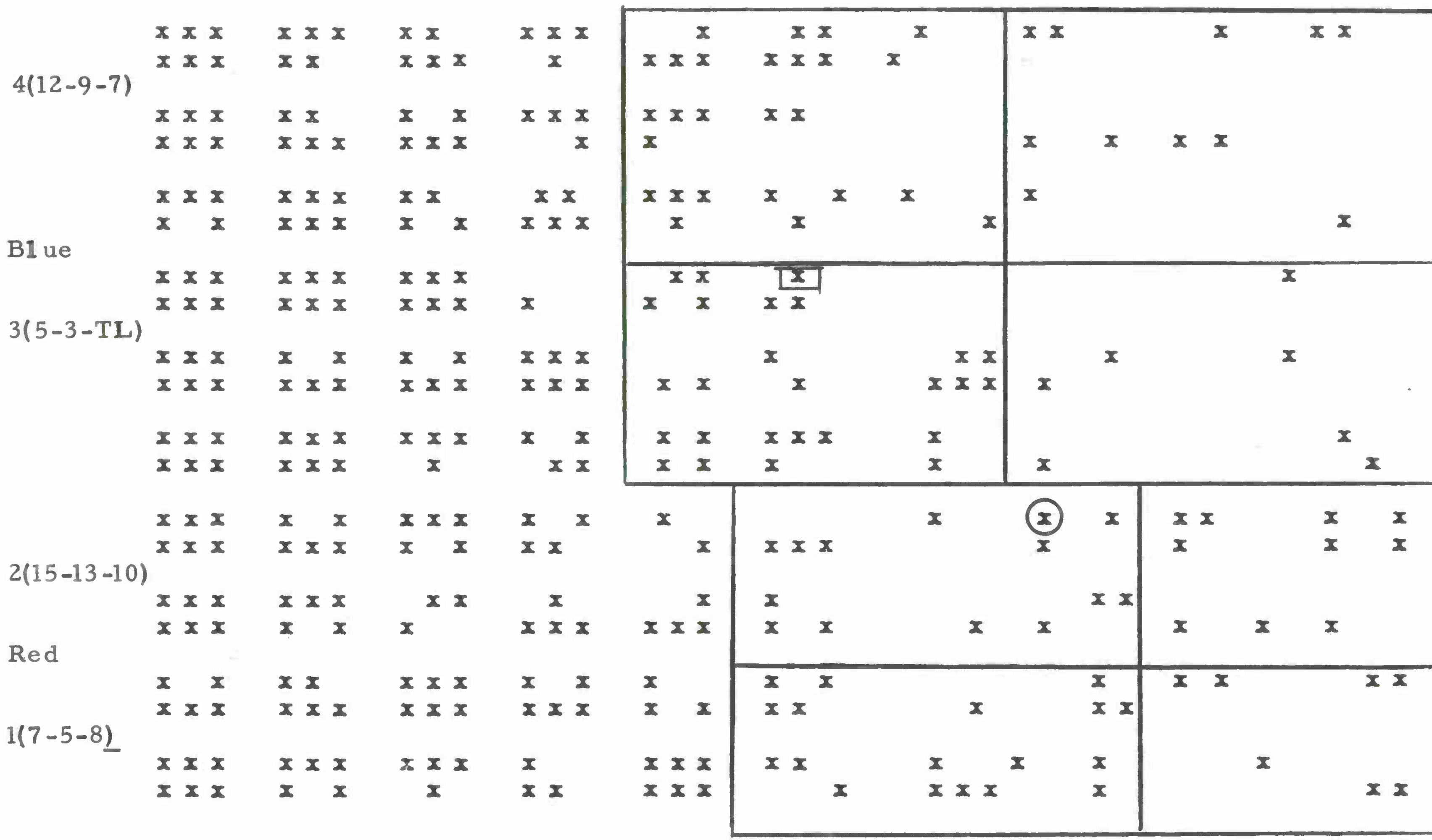
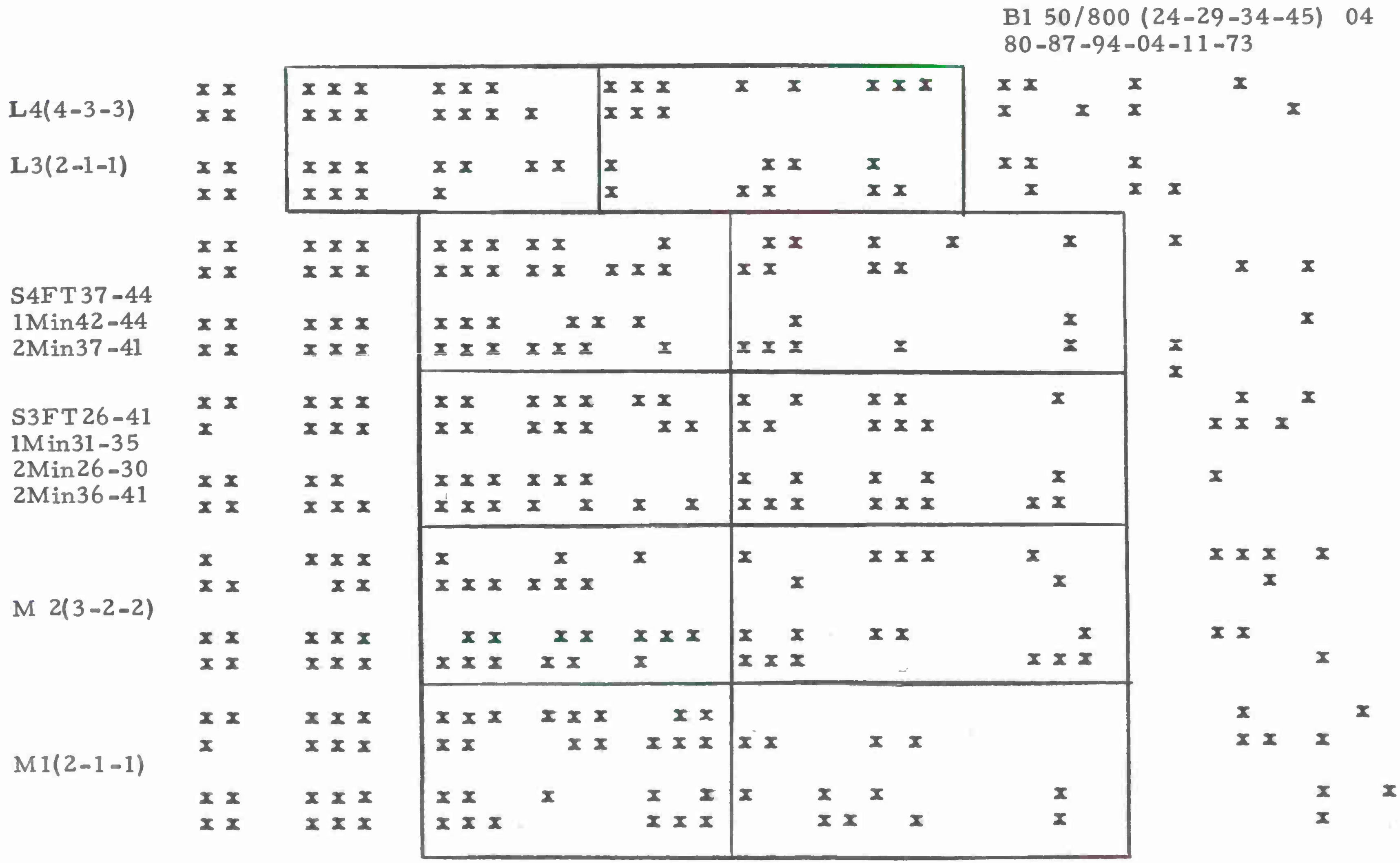


Figure 3. Sample Missile Referee Sheet



at time 30 (the second time period, between 29 and 34 (cf. (1) above), the kill or miss would take place at time 30 plus 9 or time 39 and the outcome feedback would be accomplished at that time.

4. 3 (5-3-TL) stands for site 3, same class of aircraft and the intercept times. The shorter times here indicate that track 04 is at all times closer to site 3. The "TL" indicates "too late". Thus, track 04 had penetrated the defended area at time 34 (the beginning of the third critical time period of the track) and even a kill would fail to prevent damage.

5. The upper blocked-off areas opposite these site and time labels were both for Blue-type aircraft, found at sites 3 and 4. The lower blocks have similar labels (2 (15-13-10), Red, 1 (7-5-8)) indicating the appropriate time quantities for Red-class aircraft at sites 1 and 2.

6. The columns of X's and blanks are random samples from distributions the probability of an "X" (as opposed to "no X") in which ranged in decrements of .03 in succeeding columns from .99 for the column farthest to the left of the sheet to .12 at the extreme right. The columns are arranged in sets of three. Within the rectangular blocking these sets of three columns are further grouped in threes. The lefthand set of nine columns within the blocked-off section was used in selecting outcomes for assignments of high-yield armed weapons and the right hand set of nine for low-yield armament. Within either set of nine columns, the left-most three were used in selecting outcomes for assignments of three weapons against a threat, the center set for two weapon assignments and the right most set for

single weapon assignments. Within each set of three columns, the left most was used to evaluate assignments made in the first time period of the life of the track, the center column for assignments in the second time period and the right-hand column for assignments made during the remainder of the life of the track. The single weapon set of three columns was used for evaluating "trail" assignments. (see below).

7. To follow two specific assignments against the sample track (numer 04) as examples, consider:

(a) An assignment made at time 30 and consisting of two Blue-class fighters from Base 3 with high-yield armament. The small black square in Figure 2 indicates the outcome which wouldbe selected. It was selected as the first (from the top) of those outcomes allocated to Base 3 (blocking opposite the entry 3 (5-3-TL), from the left-hand set of nine columns (high-yield armament), the center group of three columns (two weapons) and the center column of that group (second time period in the life of the track - between 29 and 34 minutes). This outcome was an "X" or a "kill" and it would take place at time 33 or assignment time (30) plus 3 minutes, the intercept time pre-programmed for assignments in the second time period for this track.

(b) An assignment made at time 27 of two Red-class fighters with infra-red seeker missiles from Base 2 to be scrambled "at trail" (i.e., one followed by a second one minute later). The small black circle in Figure 1 indicates the outcome. To select an outcome for this assignment the single-weapon group of columns (right most group), left most column (first time period), Base 2 (upper of the lower set of rectangles) Red IR set of nine columns (left hand set) was entered. The circle here is around the first outcome in that column. It happened to be an "X" or kill. The second, unused, Red fighter would be returned to inventory as "airborne available" in this case. If the first entry had been a blank, the first fighter would have missed and the next entry below it in the same column would be used to score the outcome for the second "trail" fighter.

8. Note that the longer an assignment was delayed, the fewer weapons were assigned and the lower capability the armament class or weapon class assigned the lower (i.e., farther to the right of the "table") was the kill probability. Note also that the cumulative probability of an "X" in the single weapon columns is, mathematically greater than that of an "X" in the corresponding two weapon and three weapon columns. For example, if the probability of kill of a single weapon is .50 and the kill probability of two of the same weapons at the same time is .60 (which is the way probabilities were selected for this experiment, i.e., a difference in probability of .07 between corresponding columns in adjacent sets of three columns) the mathematics of the "trail" probability of two weapons is as follows:

First weapon: P(kill) = .50 P(no kill) = .50

Second weapon: P(kill) = .50 P(no kill) = .50

P(neither kills) = .5 x .5 = .25

P(at least one kill) = 1.00 - .25 = .75

The kill probability of trail type assignments, therefore, was always higher than that of the same number of weapons in a "single flight" or simultaneously.

9. The missile referee sheets had similar markings (cf. Figure 3) L4 and L3 signifying long range missiles from sites 4 and 3, S4 and S3 similarly for short range missiles and M1 and M2 signifying mobile missiles at areas 1 and 2. "FT" followed by two numbers (e.g., FT 37-44) signifies the time period during which autonomous fire was permitted. The other data at the top right are the same as those on the aircraft sheet. Scoring was done in the same manner except that "trail" fire was not permitted.

10. It should be noted that the same action, selected at the same time against the same track would have the same outcome everytime - i.e., no matter which decision maker selected the action. This was necessary for two reasons, first to simplify scoring by the referees to the point that it could be done accurately within the time available and secondly, because the number of runs required to collect the data if a completely free operation of the probabilities was permitted would have been prohibitive.

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